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New York University
Technical Report No. 1
Constant Level Balloon
April 1, 1948

TECHNICAL REPORT NO. 1

Balloon Group, Constant Level Balloon Project

New York University

Covering the period Nov. 1, 1946 to Jan. 1, 1948

CONSTANT LEVEL BALLOON

Research Division, Project No. 93

Prepared in Accordance with Provisions of Contract
W28-099-ac-241, between
Watson Laboratories, Red Bank, New Jersey
and
New York University

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April 1, 1948

New York 53, New York

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THE BALLOON PROJECT TECHNICAL REPORT

Section 1. Introduction to Problem

On 1 November 1946, the Research Division of the College of Engineering of New York University entered into Contract No. W28-099-ac-241 with Watson Laboratories, Air Materiel Command. Under this contract, the University was commissioned to design, develop and fly constant-level balloons to carry instruments to altitudes from 10 to 20 km, adjustable at 2 km intervals.

The following performance was specified:

a. Altitude shall be maintained within 500 meters

b. Duration of constant-level flight to be initially 6 to 8 hours minimum; eventually 48 hours

c. The accuracy of pressure observations shall be comparable to that obtainable with the standard Army radiosonde ($\pm$ 3 to 5 mb)

Monthly reports have been submitted to describe the progress of the project, however, much data and details of technical nature were given only in a qualitative way. It is intended to collect these data in this technical report and to review at the same time the total achievement of this phase of the project.

Section 2. Method of Attack

A. Balloons

A survey was made of previous attempts to produce a constant-level balloon; such as, the experiments by Meisinger[1] with manned balloons, the shrouded meteorological balloon developed by Dewey and Almy[2], the Japanese balloon bombs[3], and the clusters of meteorological balloons which have been used in cosmic ray investigations by Compton, Korff and others[4].

From this survey and a study of aerostatics,[10, 15, 16] it appeared that a non-extensible balloon is highly desirable due to the vertical stability exhibited when such a balloon is full of the lifting gas: A non-extensible balloon with no diffusion or leakage through the walls, which could withstand a high internal pressure, would automatically remain at the density where the buoyancy of the full balloon equaled the load. In practice, control devices are needed to offset the leakage and diffusion of the lifting gas and to correct for the motion of the balloon due to diurnal changes of the balloon's temperature and to correct for vertical wind currents in the atmosphere. It was decided to use a plastic as the balloon fabric, since available plastics have suitable characteristics, and are also relatively inexpensive as compared to coated fabrics.

The desirable properties to be considered in the selection of a plastic balloon material are:

a. Ease of fabrication

b. High tear resistance

c. Light weight

d. High tensile strength

e. Chemical stability

f. Low permeability

g. Low brittle temperature

h. High transparency to heat radiation

Table I is a qualitative-characteristics catalog of the film and fabrics investigated. The data in the table are presented as approximations because of the great variations of a given property with choice of samples and test methods. From this study, polyethylene, nylon, saran, and neoprene-coated nylon seem to be most generally satisfactory. Eighteen plastics and balloon fabrication companies were contacted in an attempt to secure fabricators.

Table I

Fabric	Low Temp. Properties	Permeability	Tensile Strength	Tear Resistance	Ease of Fabrication	Stability to Ultraviolet
Polyethylene	Good	Medium	Low	Good	Good	Good
Saran	Fair	Low	High	Poor	Fair	Fair
Nylon	Good	Low	High	Low	Good	Good
Vinylite	Very poor	Medium	Medium	Good	Good	Good
Teflon	Believed good	Low	High	Good	Cannot be fabricated	Good
Ethocellulose	Good	Very high	Low	Fair	Good	Good
Pliofilm	Poor	High	Poor	Fair	Good	Poor
Nylon or silk fabric coated with:						
1. Neoprene	Fair	Low	High	Fair	Fair	Fair
2. Butyl rubber	Good	Low	High	Fair	Fair	Good
3. Polyethylene	Unknown --					
4. Saran	Unknown --					

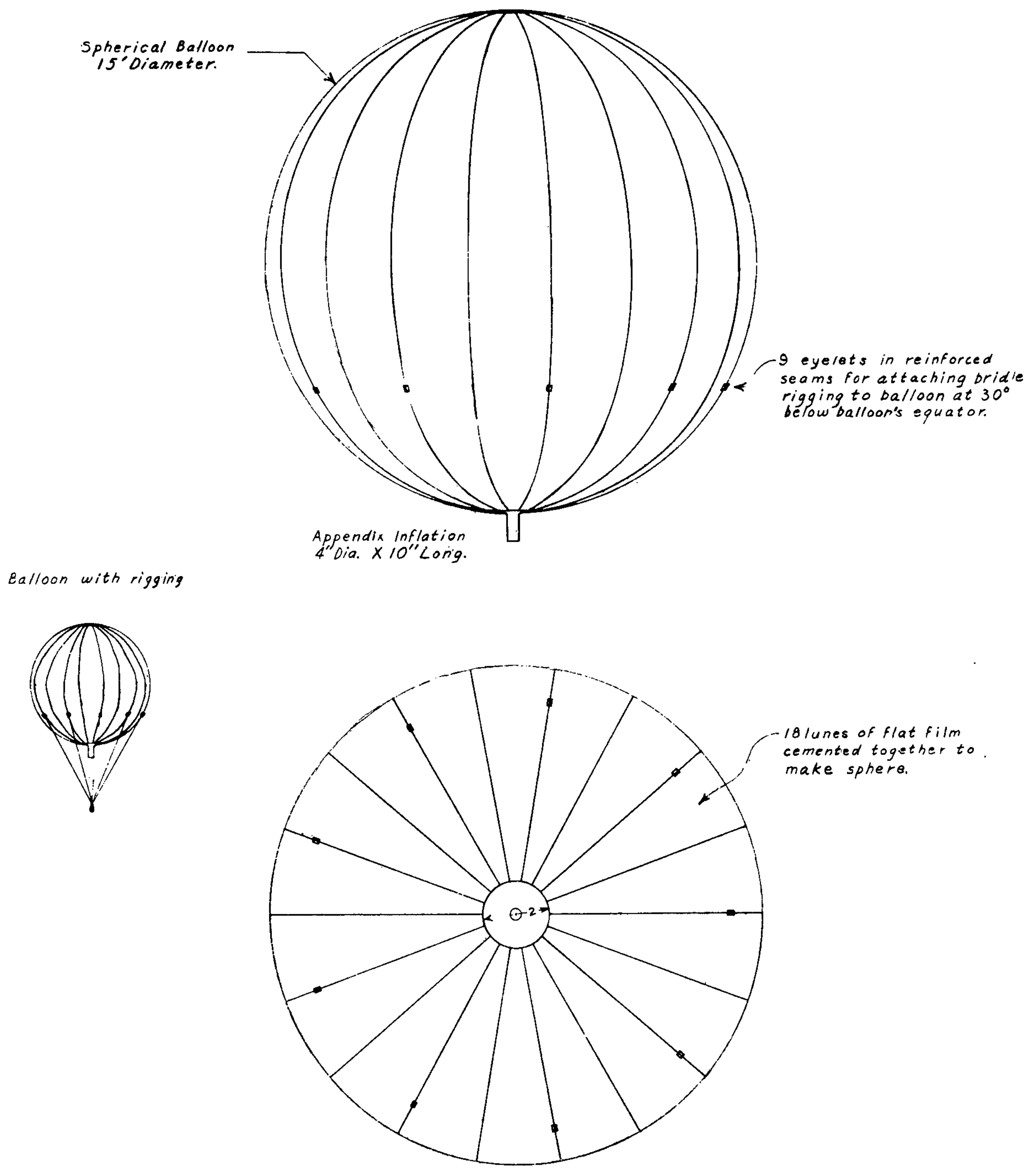
Table II shows the balloons which have been purchased from those manufacturers who expressed an interest in the problem.

Table II

Company	Film type, thickness, diameter, shape	Special Features	Unit Cost	Delivered to date
H. A. Smith Coatings, Inc.	.004 Polyethylene 3 feet diameter spherical	Proto-type	$150.00	4
H. A. Smith Coatings, Inc.	.008 Polyethylene 15 feet diameter spherical	Low Permeability	$530.00	5
H.A. Smith Coatings, Inc.	.004 Polyethylene 15 feet diameter spherical	Low Permeability	$530.00	5
General Mills, Inc.	.001 Polyethylene 7 feet diameter Teardrop.	Stressed tape type seam	$20.00	25
General Mills, Inc.	.001 Polyethylene 20 feet diameter Teardrop.	Stressed tape type seam	$125.00	47
Dewey & Almy Chemical Co.	A spherical nylon cloth shroud around a neoprene balloon.		$339.00	2

Table II is based upon final or modified orders in those cases where the rapid progress of flight technique rendered certain features obsolete before the balloons on order were delivered.

Figure 1 shows the spherical balloon as originally designed. This type of balloon was made of .004 and .008 inch, heat-sealed, polyethylene. It had several good characteristics, such as very low leakage, but the method of load attachment furnished by H.A. Smith, Inc., was not satisfactory. Of the six balloons of this type which were used, two ripped free from the shroud lines during launching.



PLASTIC BALLOON
FOR CONSTANT LEVEL BALLOON PROJECT AT NYU
APRIL 27, 1947
SCALE: 1" = 3' 0"

FIG. 1

Figures 2 and 3 show the tear-drop cell of the stressed tape design developed by General Mills, Inc. The film is .001 inch polyethylene, butt-welded, with scotch tape laid along the seam to reinforce the seal and to carry and distribute the load. These strips, which converge to the load ring at the bottom, actually support the load.

The overloading of a General Mills 20-foot balloon on Flight 12 at Lakehurst kept the lower end of the balloon open during ascent. The ceiling was greatly reduced by the resulting dilution of the helium with air. On later flights an unsuccessful attempt to minimize this mixing was made, using a 10-foot external appendix passing through the shroud lines. This appendix fouled in the rigging and twisted completely shut, causing the balloon to burst at pressure-altitude. A modification with a 10-foot appendix outside the shroud lines also failed in actual flight. Figure 4 shows this appendix construction on a General Mills balloon which is being inflated. The final style is shown in Figures 5 and 6. It consists of a 2-foot external appendix stiffened with cardboard battens. This is taped on the outside of the load ring. It serves as a one-way valve which excludes air during ascent but allows the extra helium to valve freely when the balloon is full. No external appendix can be used whenever the rate of rise exceeds 600 feet per minute. For optimum balloon performance, it has been determined that: 1) the equipment load for the General Mills 20-foot balloon should be held under 30 pounds; 2) rates of rise should be less than 900 feet per minute; and 3) for maximum altitudes an external appendix is needed; hence the limiting rate of rise is about 600 feet per minute in this case.

Several experimental flights have been made using shrouded Dewey and Almy neoprene balloons, as well as small and large experimental cells in

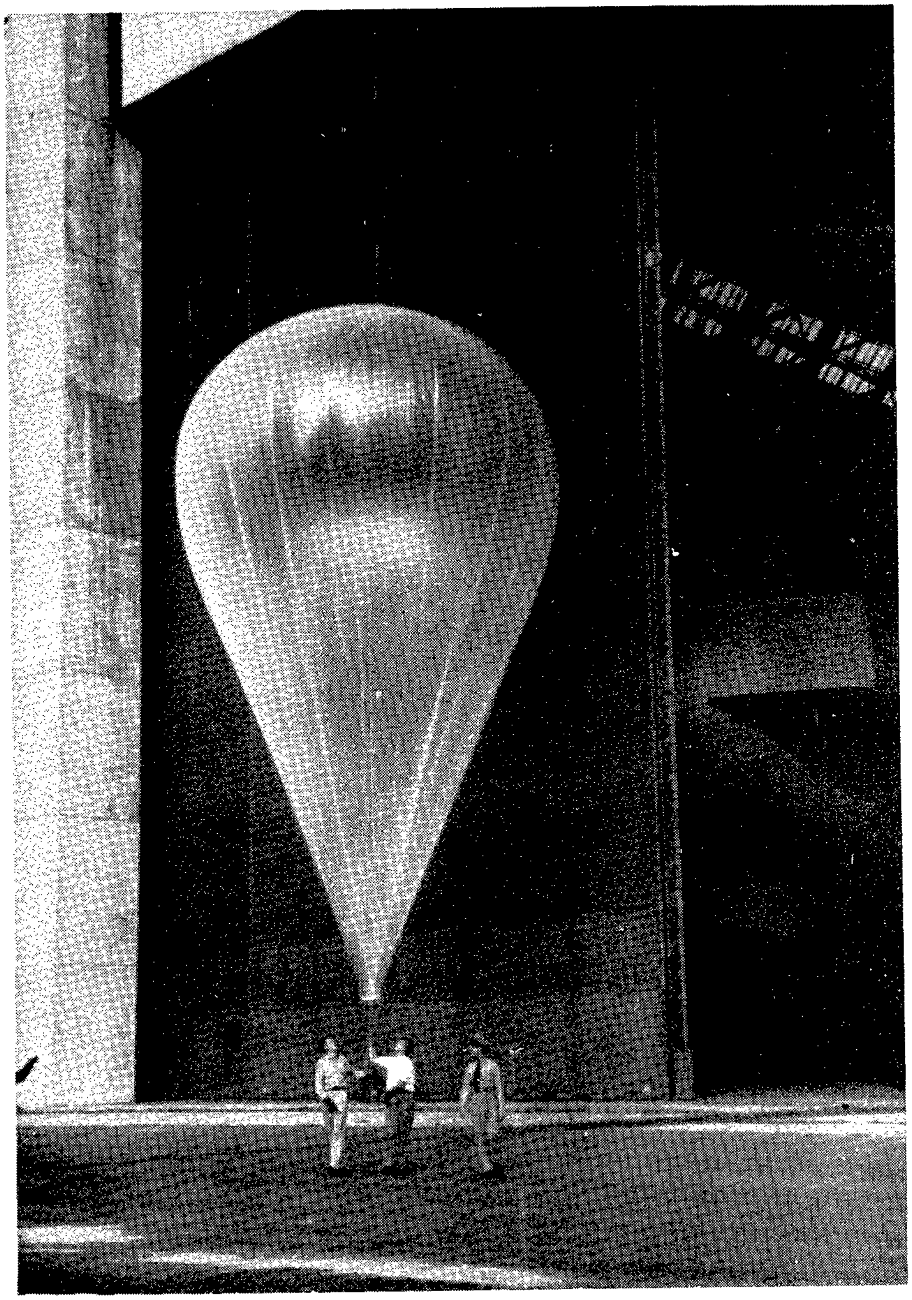


Figure 2
Teardrop, .001" polyethylene balloon, 20 foot in diameter, designed by General Mills, Inc.

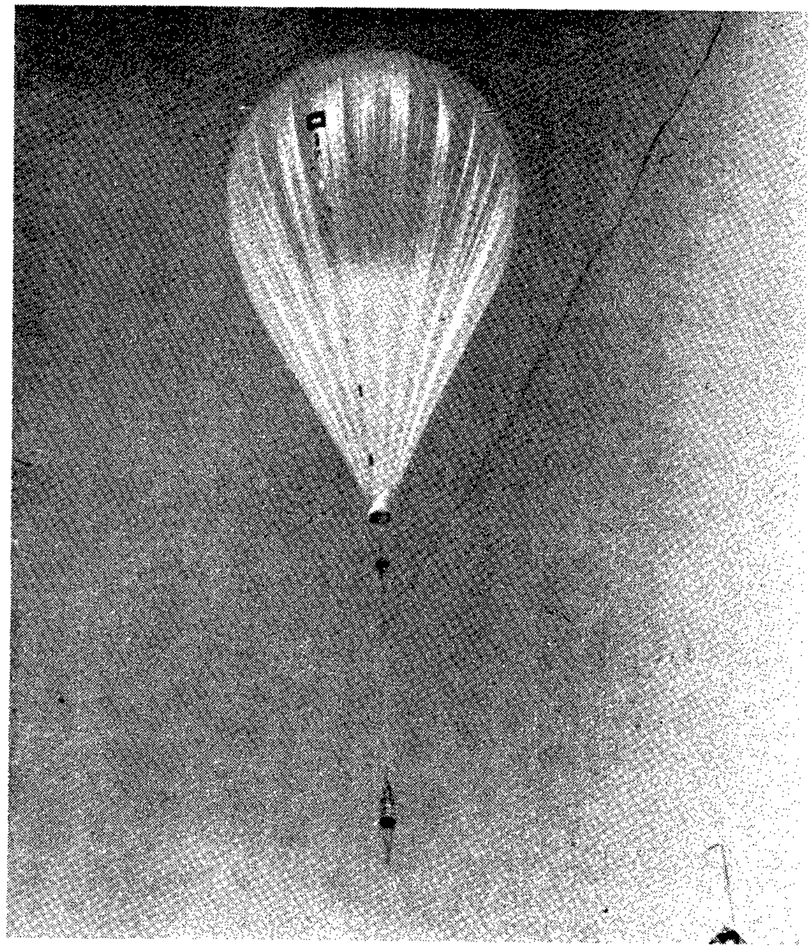


Figure 3
Twenty ft. balloon, showing
burn-out patch in place.

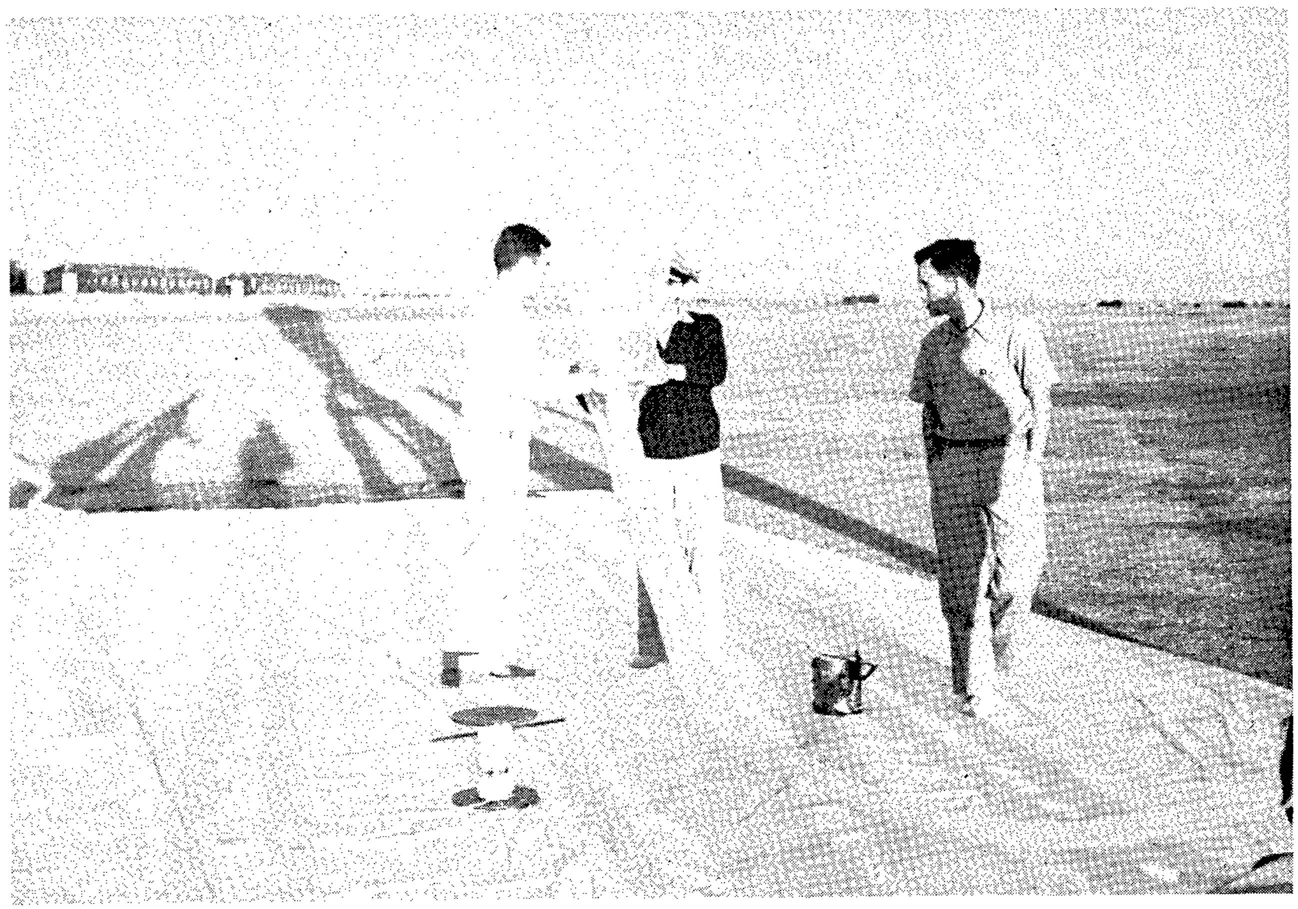


Figure 4
General Mills 20 foot balloon with 10 foot appendix.

Figure 5
Two foot appendix, stiffened, shown on a General Mills ballon. The swollen inflation tube indicates that the balloon is being filled.

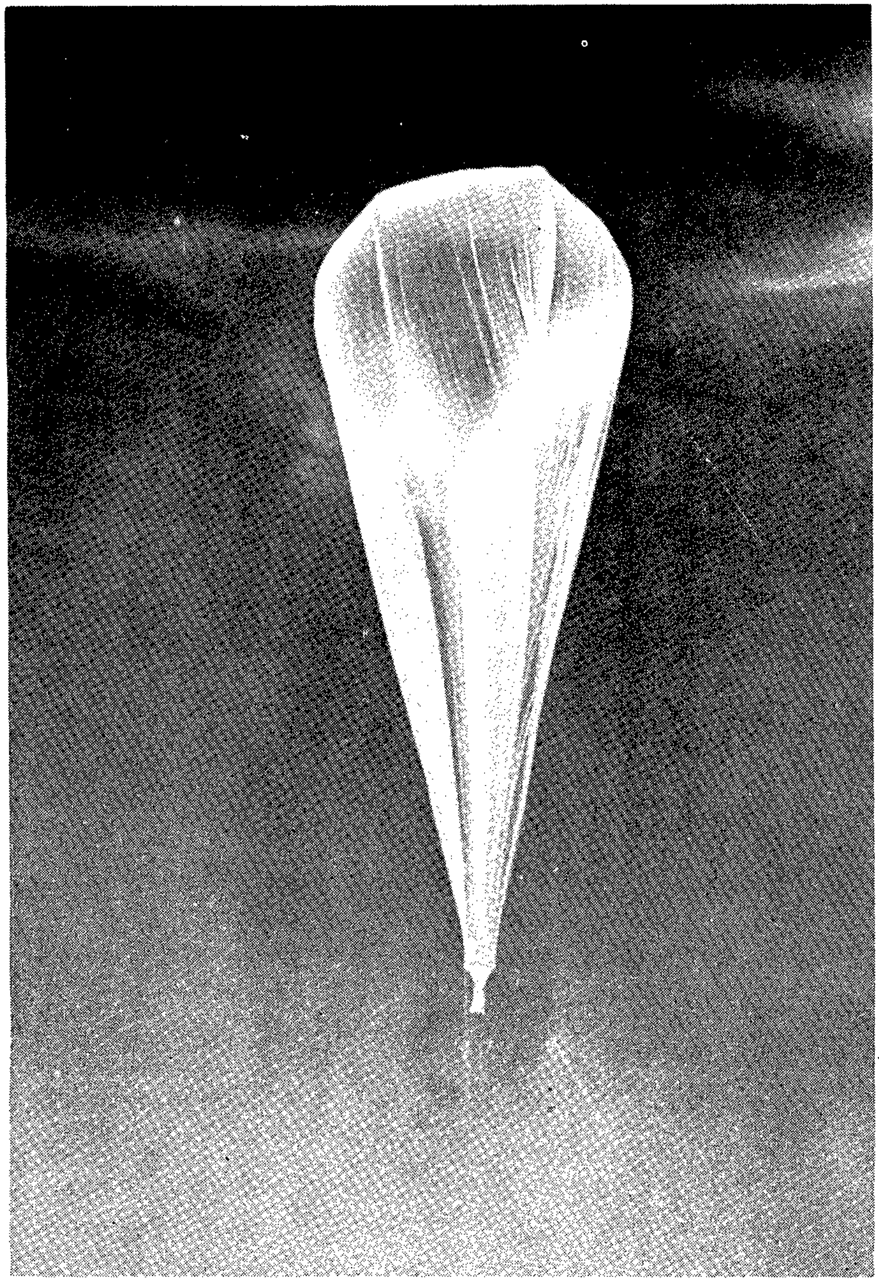


Figure 6
General Mills 20 foot balloon in
flight with 2 foot stiffened appendix.

various cluster arrangements. None of these have been too satisfactory but further investigation will be made in the field of shrouded or coated films.

B. Altitude Controls

Given a balloon capable of carrying the instruments to a desired altitude (the theory and computations involved are discussed in Section 3), there remains the problem of maintaining the cell at a constant level. The buoyancy of a gas-filled cell will decrease as the gas leaks or diffuses through the balloon wall. To hold an absolutely constant altitude, the volume of lifting gas entrapped must be maintained in an atmosphere of unvarying horizontal density, with no change in the total weight supported by the balloon and with no fluctuations of the temperature of the gas with respect to the air. The best approximation to these conditions may possibly be achieved through the use of liquified hydrogen, which would be permitted to evaporate at a rate in excess of gas leakage. The weight of equipment required to control this evaporation rate appears to be prohibitive. Liquid hydrogen, also, is not safe to handle.

Two practical methods of keeping a balloon at nominally constant altitude have been devised, both using the liquid ballast dropping technique. (Solid ballast, such as sand, does not flow well and is liable to absorb moisture which will freeze at the temperatures experienced at high altitudes. Although a few preliminary flights were made with desiccated sand, a highly refined water-free kerosene-type petroleum product, compass fluid, was found to be more satisfactory).

In the simpler control system, ballast is dropped at a pre-determined rate, aimed to slightly exceed the loss of lift of the balloon due to leakage and diffusion. If this method is successfully used, the balloon stays full because the remaining gas in the balloon has less load to support; therefore, the balloon can rise slowly until the balloon is again full and the equilibrium is again reached between the buoyancy and the load. In the General Mills 20-foot balloon, for example, diffusion losses equal about 300 grams per hour; the balloon at its ceiling of 50,000 feet, with a 30-pound payload, risea about 900 feet with each kilogram of ballast dropped. This means that a balloon, using the simple ballast-dropping technique, will float at a ceiling which rises at the rate of about 360 feet per hour. An idealized flight of this type is shown in the solid curve of Fig. 7., neglecting the oscillation shown at sunset.

The "manual ballast valve" which was developed for this simple control system is shown in Fig. 8. This valve can be adjusted prior to balloon release to allow any predetermined flow of compass fluid up to 2000 grams per hour. The filter housing and ballast reservoir used with this valve are shown in Figures 9 and 10. This method is good where 1) a slowly rising ceiling can be tolerated, and 2) the flight does not have to go through a sunset while at its ceiling.

For economy of ballast, hence longer flight duration, it is desirable to keep the constant flow as close as possible to the total loss of buoyancy resulting from diffusion and leakage. This means that whenever rapid loss of buoyancy occurs, due to changes in solar radiation, the manual ballast valve alone will not sustain the balloon. When the balloon is suddenly cooled, due to sunset or clouds cutting off insolation (loss of superheat), the heavy loss will start the balloon downward and only a rapid expenditure of ballast will check its fall and restore its stability.

The second type of ballast dropping control has been devised to operate on a demand basis, when such a descent occurs. This control is called the automatic ballast valve. Figures 11, 12 and 13 show the appearance and design of this pressure-actuated needle valve.

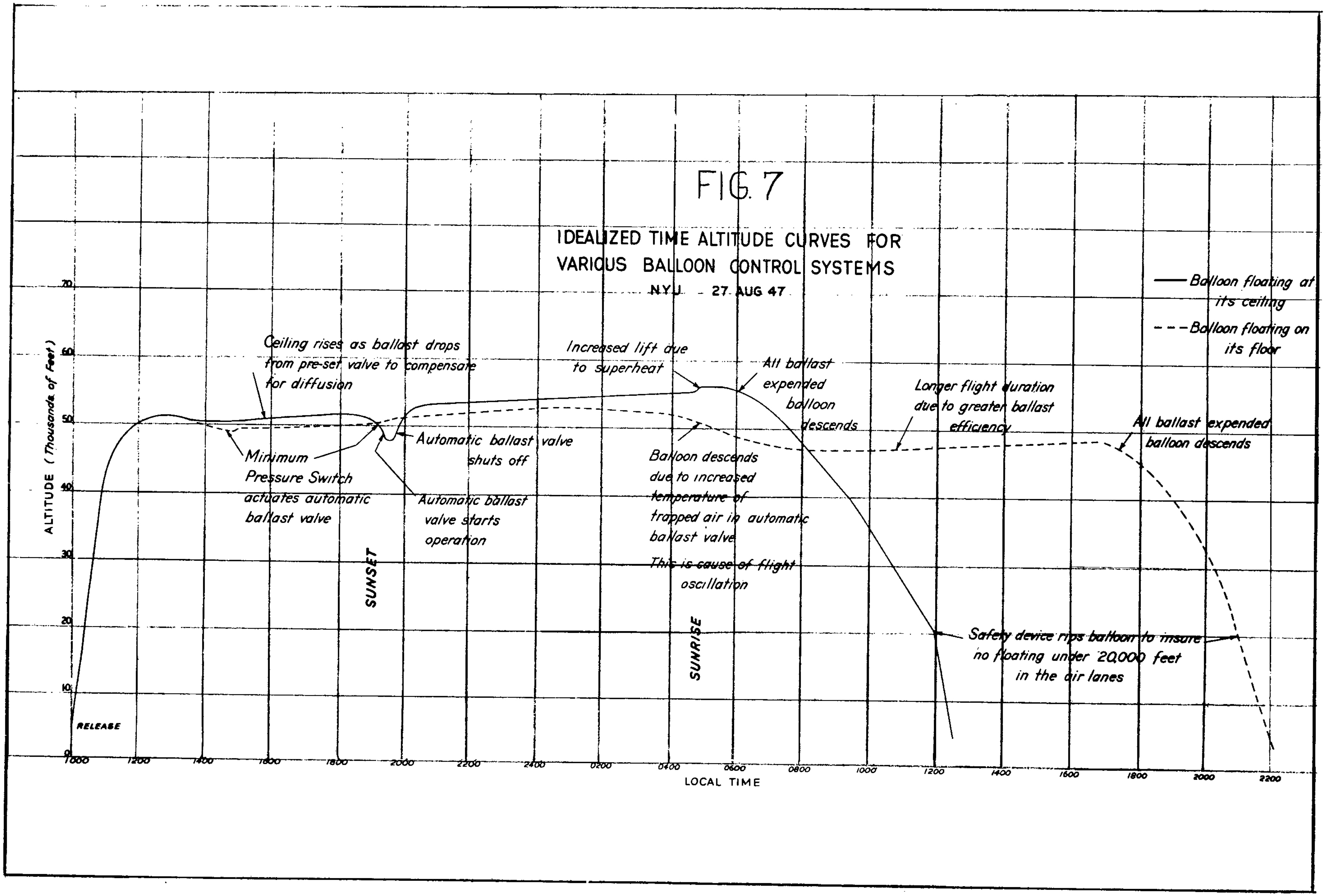


FIG. 7

IDEALIZED TIME ALTITUDE CURVES FOR VARIOUS BALLOON CONTROL SYSTEMS

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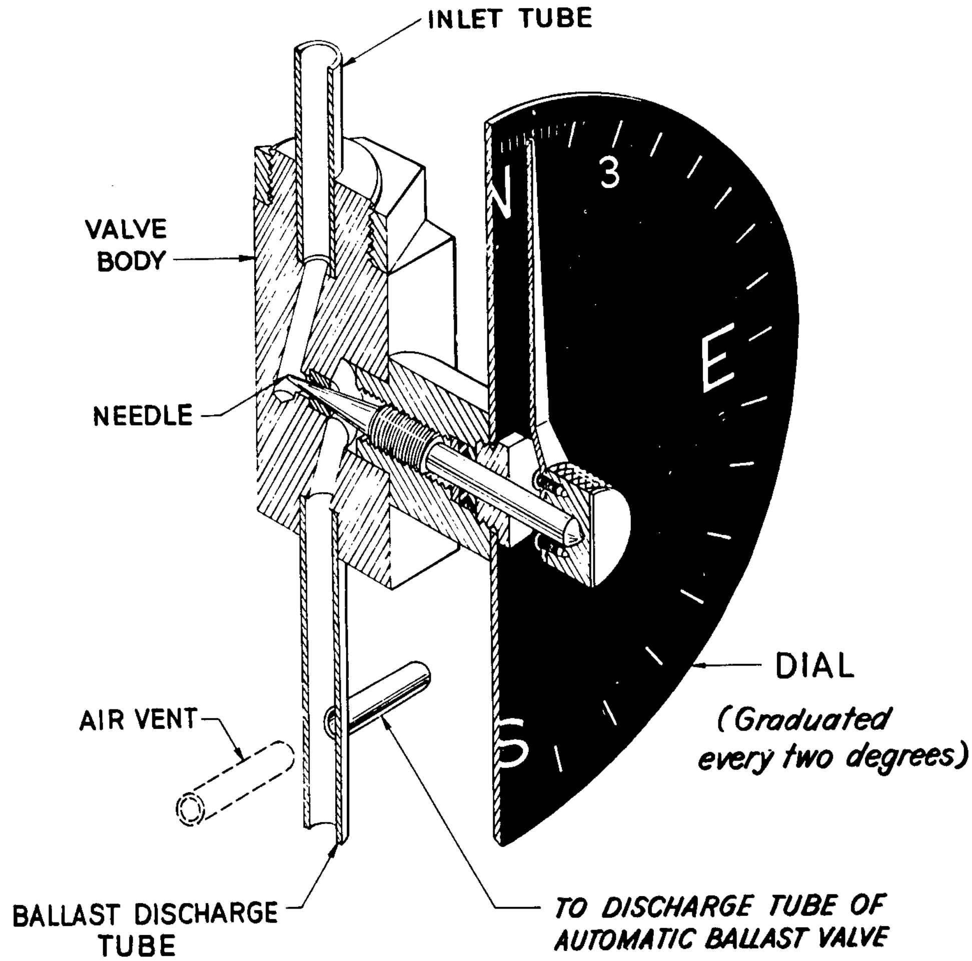

MANUAL BALLAST VALVE

FIG. 8

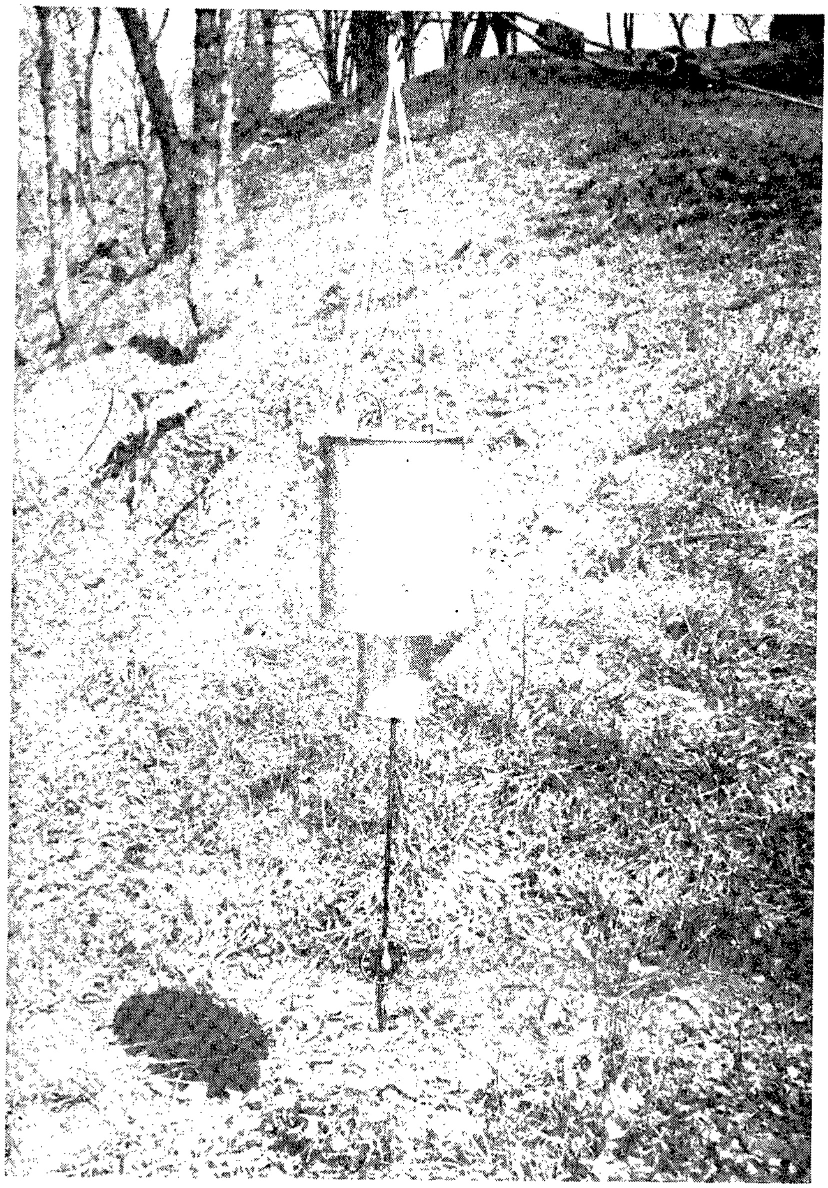

Figure 9
Fixed rate, manually operated
ballast release assembly.

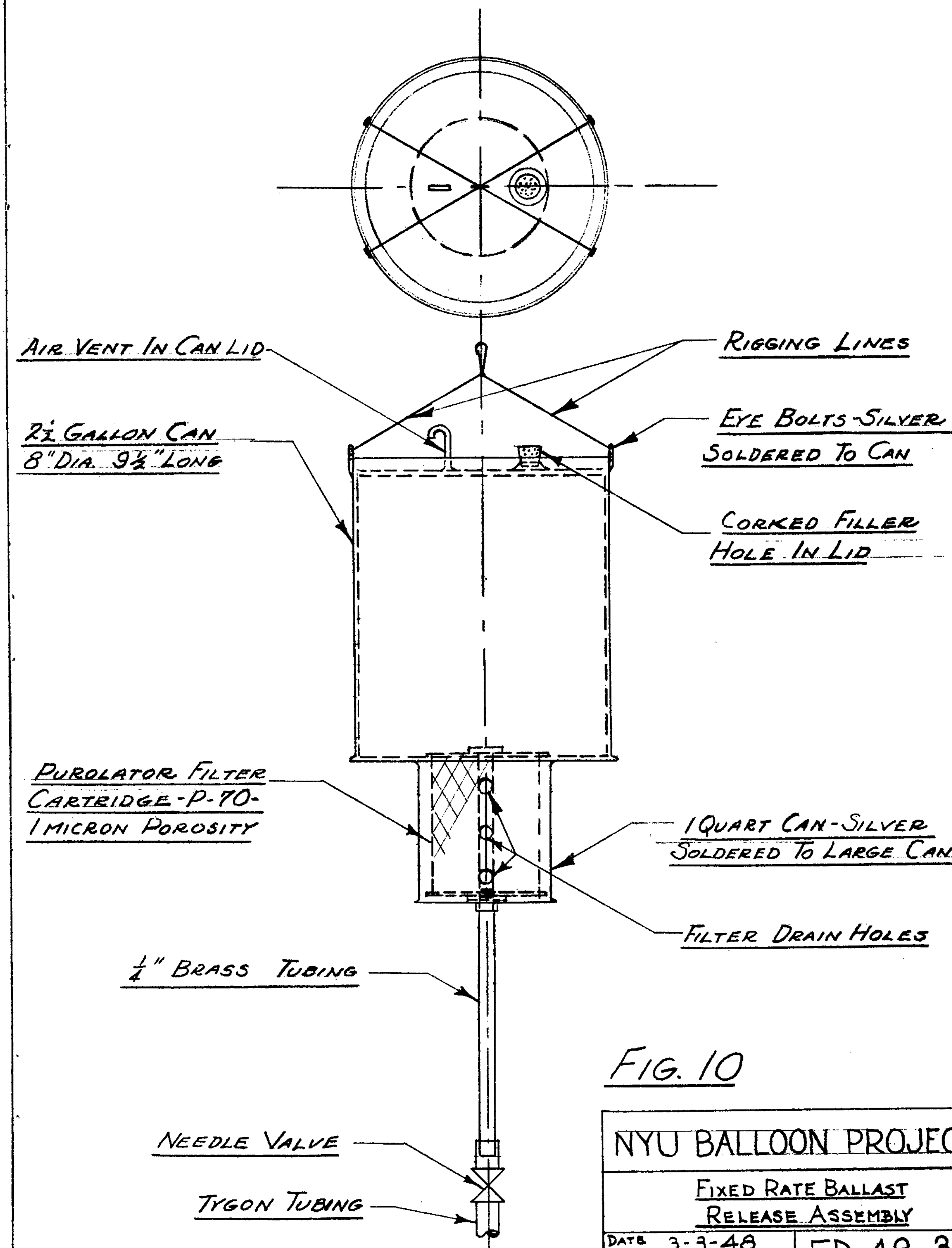

FIG. 10

NYU BALLOON PROJECT

FIXED RATE BALLAST RELEASE ASSEMBLY

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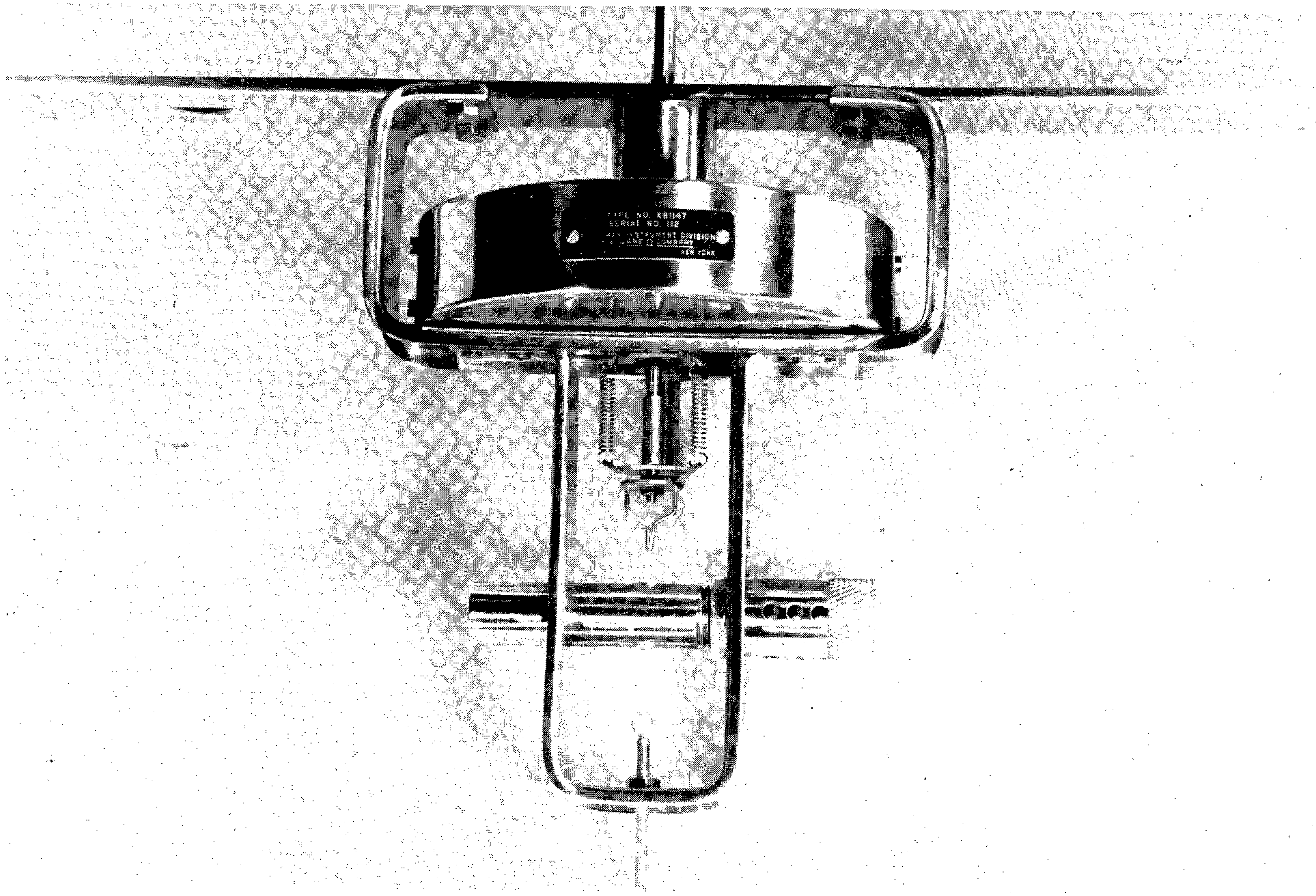


Figure 11
Automatic ballast valve.

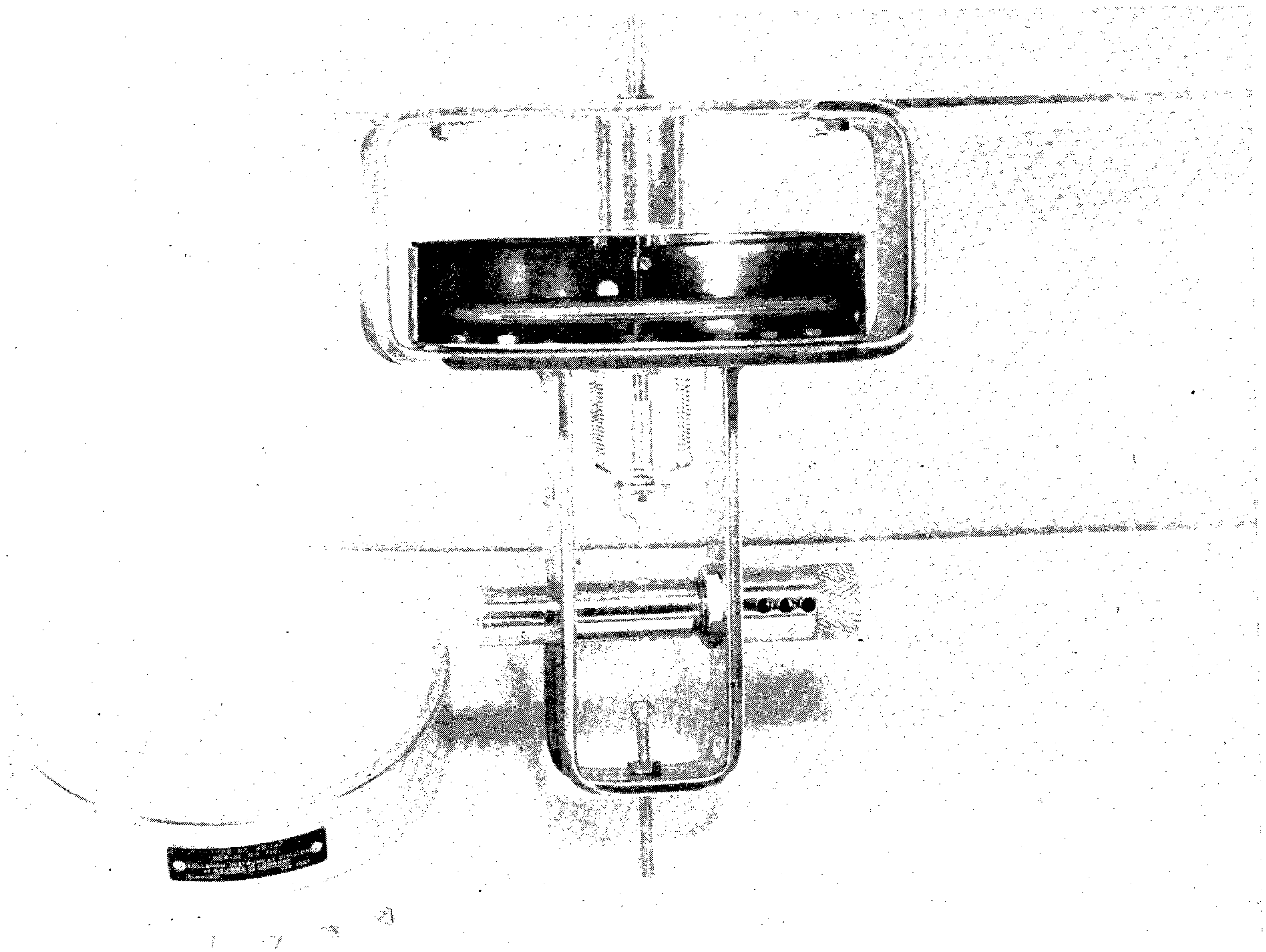


Figure 12
Automatic ballast valve, showing loading diaphragm.

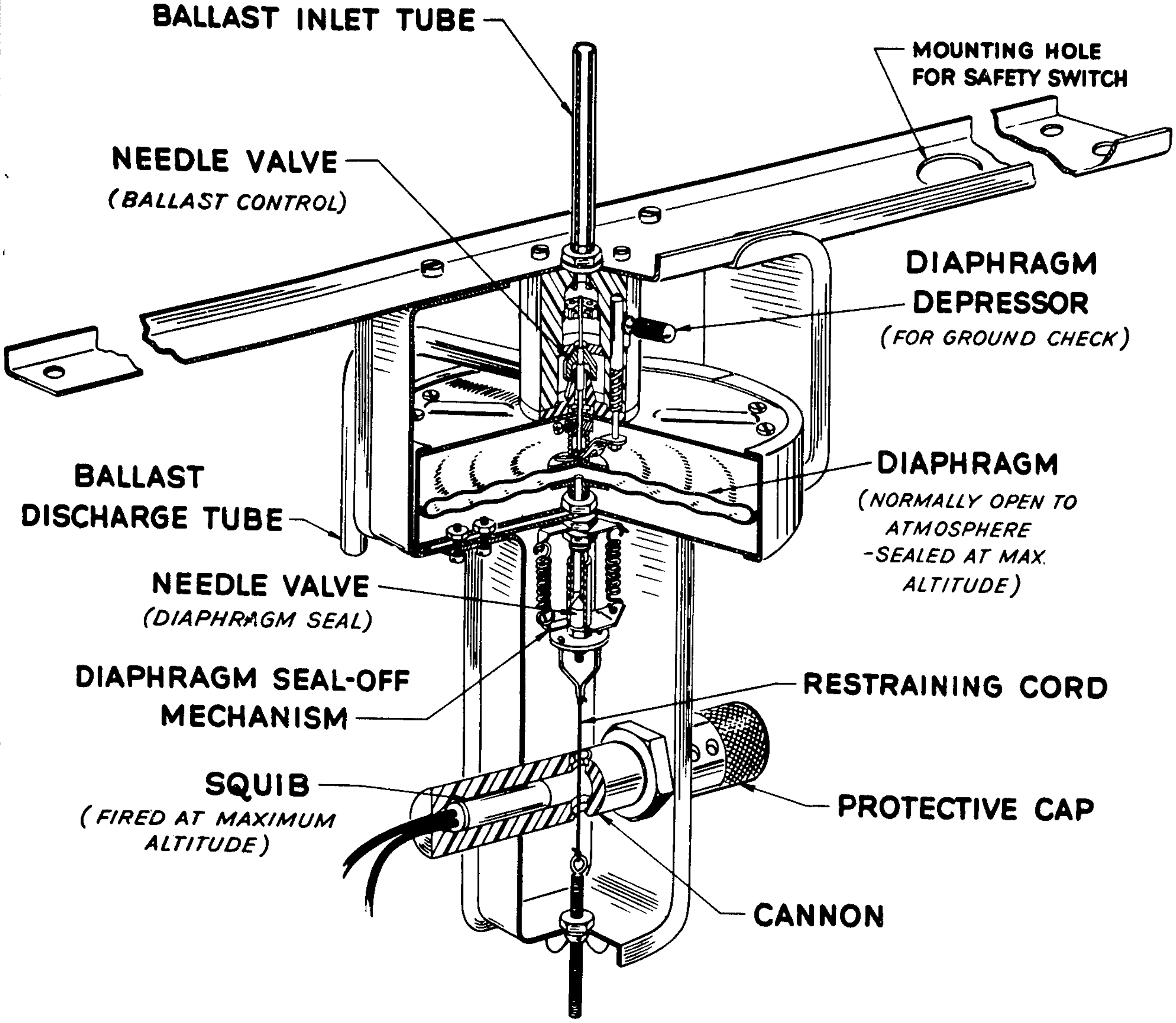


FIG. 13

AUTOMATIC BALLAST VALVE

N.Y.U. - 19 JANUARY 1948 - PINCUS

When the atmospheric pressure outside the diaphragm increases to 5 mb. above the internal pressure, compass fluid will be discharged at the rate of 160 grams per minute under a 1-foot head. When the automatic ballast valve is completely open (at 6.5 mb. pressure differential), 300 grams per minute will flow.

The automatically operated needle valve is held closed by a loaded diaphragm until the balloon reaches altitude. This diaphragm is open to the atmosphere until the balloon descends from the minimum atmospheric pressure attained. At that time, an electrical contact is made, firing a squib which seals the diaphragm mechanically from any further access to the external air. Thereafter, the capsule contains a volume of air which has been trapped at the pressure and temperature existing at the time of operation of the sealing switch. When the ambient pressure increases to the point where the entrapped air is compressed below this original volume, the diaphragm will withdraw the ballast control needle valve allowing ballast discharge to occur.

Figure 14 shows the minimum pressure switch which makes the electrical contact at the time of seal-off. It consists of a trapped volume of air that is allowed to escape through a mercury pool as long as the outside pressure is decreasing. As soon as the exterior pressure increases, mercury is drawn into the tube making the seal off contact between two electrodes.

The dimensions of the air chamber and capillary tubing are chosen so that during operation the change in the volume of the air would be less than one one-thousandth of the original volume. The distance between the two electrodes (one under mercury, the other within the capillary tubing) was influenced by considerations of safety and sensitivity. If the distance is less than 6 mm., shaking during launching is likely to move the mercury

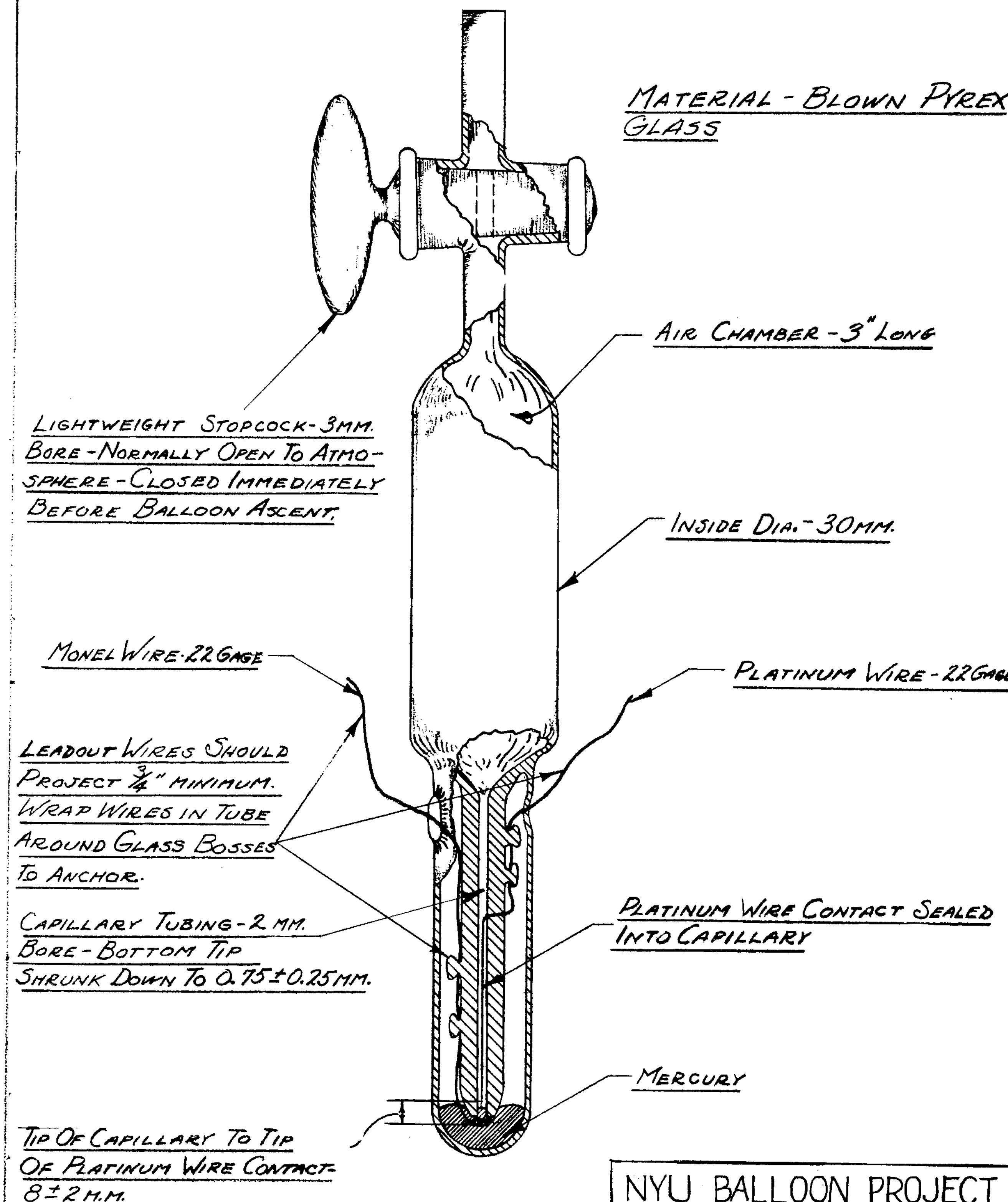


FIG. 14

NYU BALLOON PROJECT	
MINIMUM PRESSURE SWITCH (MERCURIAL)	
DATE: 3-9-48 SCALE: FULL DWN. BY J. G.	ED 48-33

sufficiently to cause a short between the electrodes, firing the squib prematurely. If the distance is too large, however, there will be too great a height difference between the time of minimum pressure and the time the electrodes are shorted. For instance, a spacing of 10 mm. would delay the firing of the squib until the pressure reached 13.3 mb. above the minimum pressure. At an altitude of 50,000 feet, the equivalent height (standard atmosphere) would be about 2300 feet. It is obvious that for high level flights, a less dense and lower freezing electrolyte for the minimum pressure switch will be needed to obtain the desired sensitivity of 2000 feet.

By adding the pressure-activated automatic ballast valve to the manual ballast valve, the complete pattern of the solid curve in Figure 7 may be achieved ideally. At sunset the rapid cooling causes descent which cannot be compensated for by the manual ballast valve. As soon as the seal-off pressure of the automatic ballast valve is exceeded by the atmospheric pressure, ballast flow is begun, which restores the balloon to its ceiling.

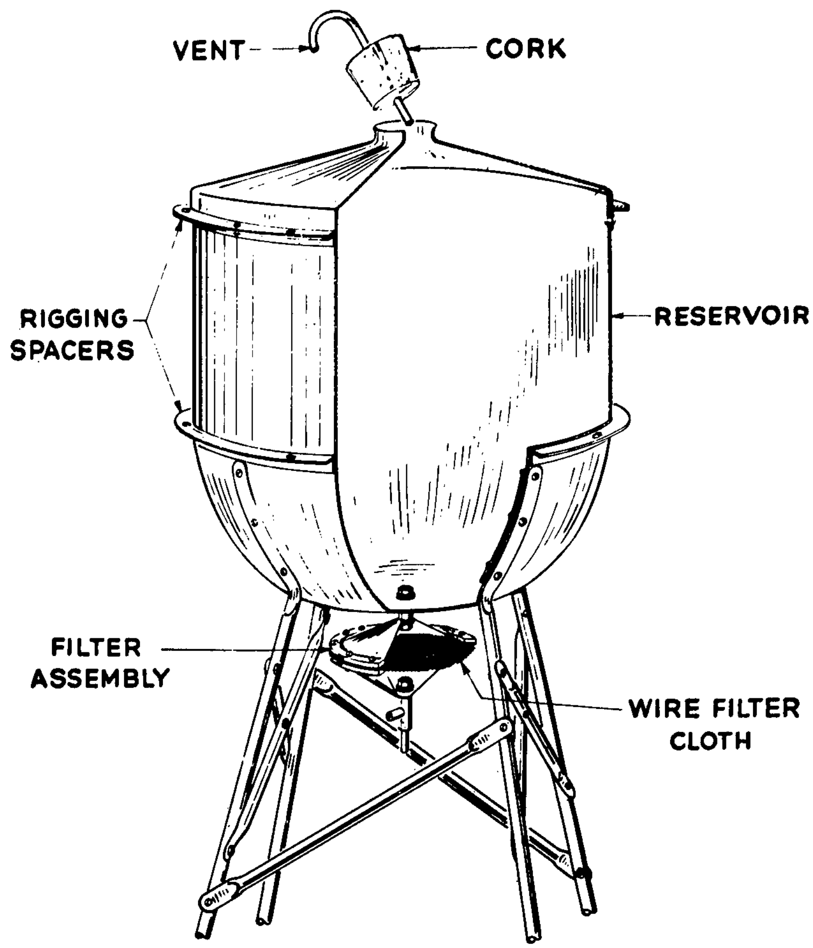
The dashed curve in Figure 7 shows the action of a balloon when the automatic ballast valve alone is used for control purposes. In this case the balloon will sink slowly from its ceiling (where full buoyancy just equals the load) to the level where the automatic ballast valve drops ballast at a rate equal to the diffusion (the floor). It will be noted that a flight which is controlled in this manner is less wasteful of ballast and results in a correspondingly longer flight. The "floor" determined by this valve varies diurnally as the temperature (hence pressure) of the air entrapped in the diaphragm is affected by solar radiation. The amplitude of this diurnal oscillation may be as much as 6000 feet, the night level being higher than the day level.

To reduce the effect of varying fluid heads and a corresponding variation in valve calibration, a ballast reservoir mounting was devised to limit the head values. This ballast reservoir, after several modifications, consists of a spun aluminum tank with filter, mounted on 18-inch legs. It is shown in Figure 15. The legs serve as supports for the other control units and a head of at least one foot is provided by tubing to the automatic ballast valve. The capacity of the reservoir is approximately five gallons. Figures 16 and 17 show the complete ballast release assembly.

One other system of altitude control may be mentioned. This is the method used by Korff and others[4] to roughly approximate constant level flights for cosmic ray investigations. A number of meteorological balloons are inflated until they will just support the flight load. A few other balloons are added to the train to give a free lift appropriate for the desired rate of rise (see Computations, Section 3). At some time after release these "lifter" balloons burst due to over-inflation, or are released by a pressure or time-activated mechanism. If the original balance was correct, and the effects of superheat and diffusion cancel each other, the cluster of cells may float. When one or more of the balloons breaks, or leaks excessively, the train will descend. Although this method was used in early experimental flights it proved to be useful only as a stop-gap method of carrying gear aloft for test purposes. No modification of this basic technique seems likely to produce even a consistant flight pattern due to the uncertainty of properties and behavior of these inherently unstable balloons.

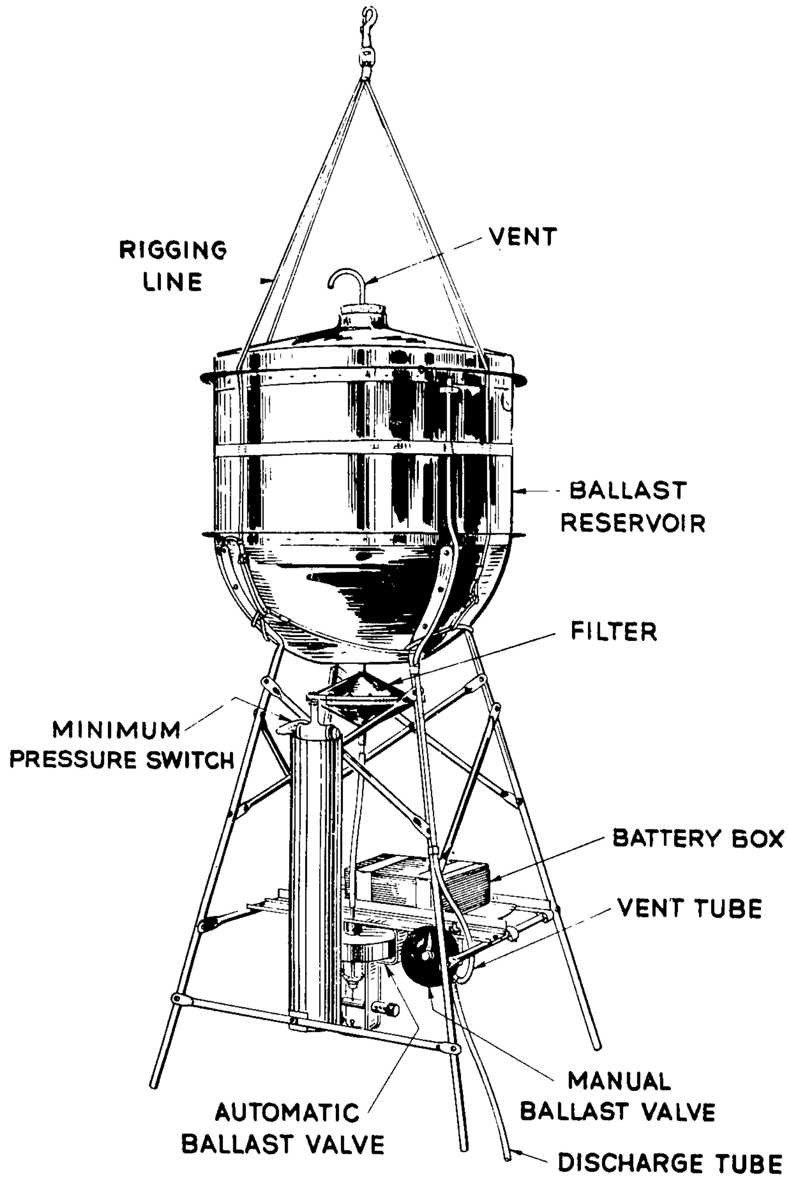
C. Altitude Determination

In order to evaluate the performance of the basic control apparatus, an investigation of pressure-measuring equipment and telemetering gear has been made. The problems of measuring upper-air conditions in general



BALLAST RESERVOIR

FIG. 15



BALLAST RELEASE ASSEMBLY

FIG. 16

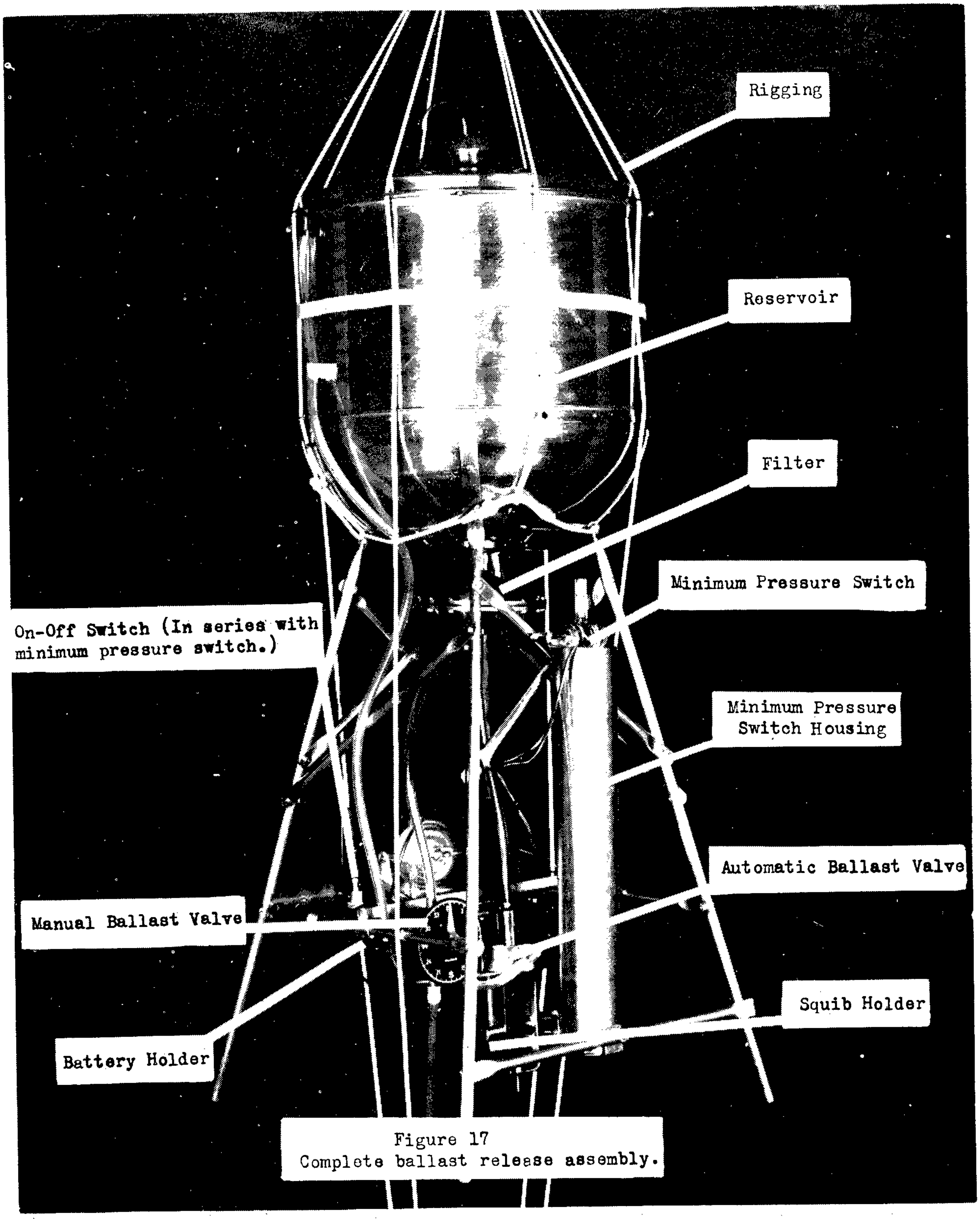


Figure 17
Complete ballast release assembly.

may differ markedly from the problems of surface measurement. For example; for any instrument used on a floating balloon, some consideration must be given to the effect of solar radiation on its behavior. As mentioned in the discussion of the automatic ballast valve, this effect is especially important in the action of any aneroid or other capsule which is not completely temperature compensated. Since the floating balloon will remain within one parcel of air, rising and falling and moving sidewise as the air does, temperature extremes will result from radiation effects and lack of ventilation. One investigator[9] has estimated that the temperatures to be experienced by such a body range from -60°C after a night of radiation to a maximum of +50°C in direct sunlight. Two ways of partially circumventing the undesirable results of this feature are:

1. Temperature compensation of the pressure capsule for some pre-set pressure. This compensation is only complete at one pressure.[5]
2. A second method of reducing insolation effects is the use of highly reflective shields.

The methods of height determination used so far are not completely satisfactory. Pressure-heights have been obtained by 72 mc. and 397 mc. radiosonde transmitters with long-life battery packs. Difficulties have been experienced in all long flights due to:

1. Signals being lost due to excessive range or to power failure.
2. When the balloon begins to float and height oscillations result from the action of the automatic ballast valve, it is impossible to identify the radiosonde contact (hence the pressure) using the conventional baroswitch of the Diamond-Hinman type radiosonde.

These steps are now being taken to improve height measurements:

1. The addition to the flight train of a light-weight barograph.

This could provide up to 40 hours of pressure-time data if recovered. At present, about 60 percent of the flights have been recovered.

2. The adoption of a time-interval or Olland-cycle radiosonde system for telemetering pressure data.

3. Expansion of the network of ground tracking stations equipped with SCR-658 direction finding sets to increase reception of data telemetered. Figure 18 shows the area to the east of Alamogordo, New Mexico, and the probable boundaries of flight paths following release from the Alamogordo Army Air Base. Table III shows the prevailing wind data on which these probable boundaries are based. Also shown in Figure 18 are the desirable locations for SCR-658 sets and the overlap of reception ranges which could be expected, using stations at Alamogordo, Roswell, New Mexico; Hobbs, N.Mex.; and Big Springs, Texas.

TABLE III

AVERAGE WIND INTENSITIES IN BEAUFORT SCALE AND WIND DIRECTIONS AT ELEVATIONS TO 10,000 METERS FOR NOVEMBER AND DECEMBER 1944 AND 1945

NOVEMBER

	Year	Surface	1,500 M	3,000 M	5,000 M	10,000 M
El Paso	1944	N-3	NE-1	WSW-5	W-7	--
	1945	N-3	WSW-3	WSW-5	W-7	--
Roswell	1944	S-1	WNW-3	W-4	--	--
	1945	S-3	SW-1	WNW-5	W-7	--
Albuquerque	1944	SE-3	--	W-3	W-6	W-9
	1945	N-3	--	WNW-5	W-8	W-9
Amarillo	1944	SSW-4	W-4	WSW-5	W-7	WSW-11
	1945	SW-4	SW-4	W-6	WNW-9	--
Big Spring	1944	--	WSW-4	WNW-4	W-7	WSW-9
	1945	--	SW-3	W-6	WNW-7	--
Abilene	1944	--	--	--	--	--
	1945	--	--	--	--	W-10

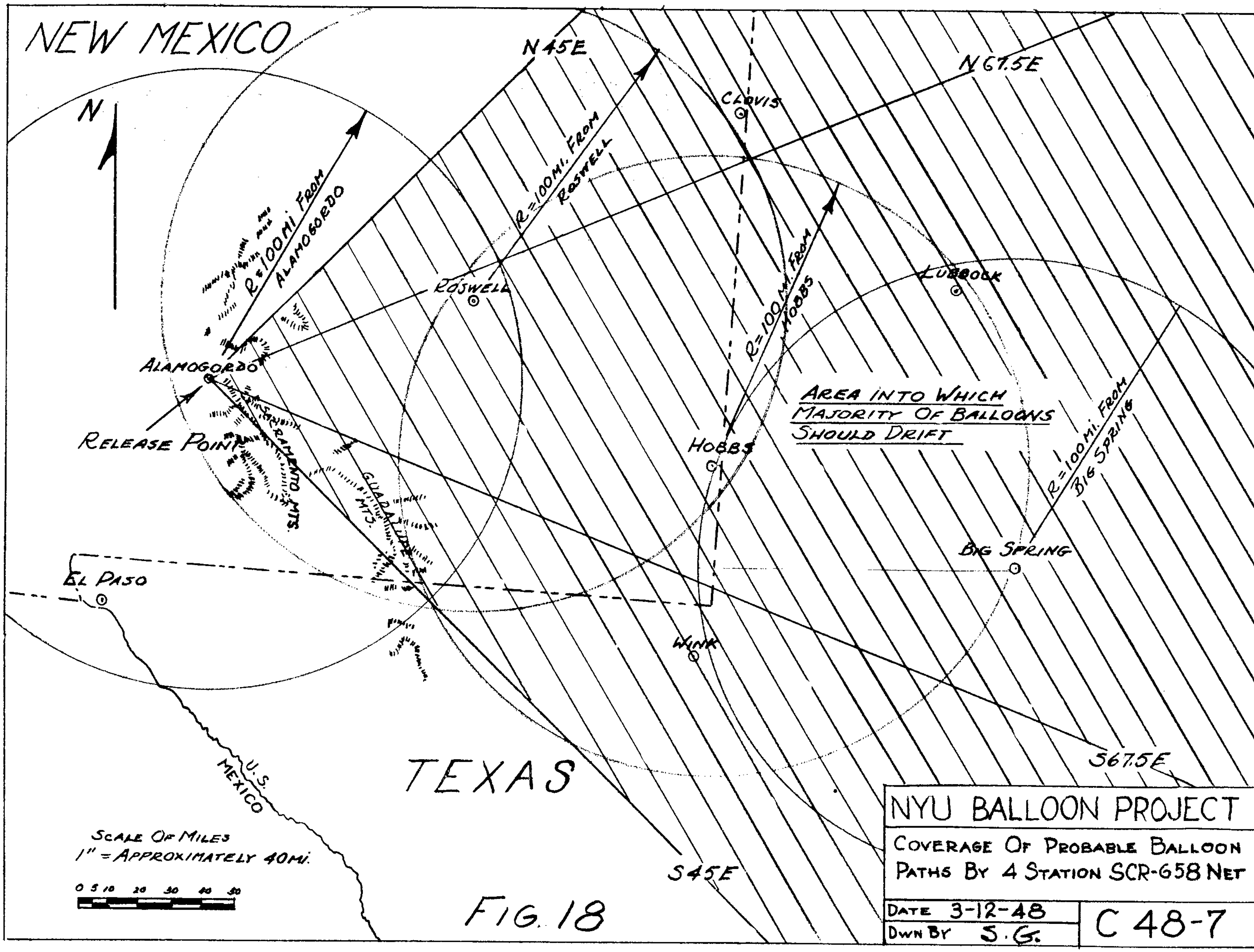

NEW MEXICO
N
N45E
N67.5E
CLOVIS
R=100MI. FROM ALAMOGORDO
R=100MI. FROM ROSWELL
R=100MI. FROM HOBBS
R=100MI. FROM BIG SPRING
ROSWELL
LUBBOCK
ALAMOGORDO
RELEASE POINT
SACRAMENTO MTS.
GUADALUPE MTS.
AREA INTO WHICH
MAJORITY OF BALLOONS
SHOULD DRIFT
HOBBS
BIG SPRING
EL PASO
WINK
TEXAS
U.S.
MEXICO
S67.5E
S45E
SCALE OF MILES
1" = APPROXIMATELY 40MI.
0 5 10 20 30 40 50
NYU BALLOON PROJECT
COVERAGE OF PROBABLE BALLOON
PATHS BY 4 STATION SCR-658 NET
DATE 3-12-48
DWN BY S.G.
C 48-7

FIG. 18

DECEMBER

	Year	Surface	1,500 M	3,000 M	5,000 M	10,000 M
El Paso	1944	N-3	NNE-1	W-2	NW-1	--
	1945	NNE-3	W-3	WNW-6	WNW-6	--
Roswell	1944	S-1	NW-3	NW-4	WNW-6	--
	1945	SSE-3	WSW-2	WNW-5	WNW-8	--
Albuquerque	1944	N-3	--	WNW-4	WNW-6	W-10
	1945	N-3	--	NW-6	WNW-8	WNW-9
Amarillo	1944	NW-4	NW-4	WNW-5	WNW-6	WNW-8
	1945	SW-3	W-2	WNW-5	WNW-9	--
Big Spring	1944	--	NW-4	NW-5	WNW-6	--
	1945	--	WSW-3	W-6	WNW-7	--

D. Tracking Devices: Horizontal

The flights made in the early part of this program were tracked optically with theodolites. Coupled with the height data, theodolite readings provide a fairly reliable horizontal locus of the balloon. However, even in the clear air of New Mexico, this method is useful for not more than 100 miles and, unless accurate height data are available, theodolite stations provide useful data for not more than 40 miles.

Aircraft observations have been used with some success when the ceiling of the balloon is not too great. It is expected that an inverted AN/APQ-13 radar, mounted atop a B-17, will greatly augment the horizontal tracking and will be of some value in determining height.

The most useful equipment for determining horizontal movement of the balloons has been the SCR-658 radio direction finding set. Long after the vertical angles registered by this gear are questionable (due to reflections off intervening terrain), the horizontal angles are useable. Used in sets of two or more, or coupled with height data, these observations give good positions with distances up to 150 miles. Figure 18 shows the coverage a network of four of these sets would provide. In contrast to the theodolites and aircraft observations, these instruments are perfectly operative when the balloon is not visible due to haze, cloud cover, etc. Ground radar has been used, when available, with fair results, particularly when radar targets are added to the flight train.

E. Flight Termination Control

Due to the size and weight of the balloons and the flight gear, the Civil Aeronautics Authority was advised of the testing program. At a meeting in New York on 20 March 1947, the New York Air Space Sub-Committee prescribed a procedure which was designed to minimize the hazard to air traffic. Similarly, the Fort Worth Sub-Committee established a procedure for flights made within the Fort Worth Region of the CAA. Pertinent correspondence with the CAA is included in the Appendix, Part 2. Owing to the size of these cells, a very slow rate of descent should be expected after all ballast has been expended and the flight control devices have ceased to operate. Thus a large balloon and several heavy pieces of equipment might take an hour or more to descend through the levels of air travel. Despite the extreme improbability of midair collision, it is obviously desirable to take all possible precautions against such mishap and current flights have the following safeguards: (1) Flights are released on days when cloud cover is forecast to be light, thus permitting visual contact. (2) Notices to airmen are to be issued if the balloon is descending within designated regions of dense air traffic. (3) To reduce the time involved in a final descent, a special device called the "blowout patch" has been developed. This is an igniting squib which is fastened to the side of the cell, on the equator. Sealed in with the squib, which is fired electrically when the cell descends below 20,000 feet, is a quantity of gunpowder and magnesium. When the squib is fired, the incendiary patch blows out, allowing a rapid escape of gas through the opening. Since the patch is on the equator, the cell does not collapse but serves as a parachute to prevent extremely rapid fall and damage to the instruments. Figure 3 shows this patch in position on a balloon. Due to premature firings, a time switch hes been built into the circuit to prevent misfiring in launching. A rip device will be developed to replace the incendiary on all future flights.

Section 3. Theoretical Relationships and Computations

A. Altitude-Density Relationships

An investigation into the relationship between density of the atmosphere and altitude, with the seasonal and geographical variations experienced, was made. The basic data, mean aerological soundings, were taken from the Monthly Weather Review, 1943[6]. These basic data consisted of observed temperatures, pressures, and humidities for altitudes from the surface up to the bursting height of balloons, normally 50,000 to 60,000 feet. For altitude above this height, the highest reported temperatures for the stations under consideration were used and the pressure data were taken for the remaining altitudes up to 100,000 feet, from the N.A.C.A. Standard Atmosphere[7].

Density was expressed inversely in terms of pound molar volumes, as this relates volume in cubic feet to buoyancies of gases of varying purity, using fundamental data. Using the simple gas laws, the molar volume of dry air at each altitude was computed in the following manner:

Given: (1) The pound molar volume of any gas at standard conditions=359 $ft.^3$

(2) From the mean sounding data at 49,200 ft. (15 km.) over Lakehurst, N.J. (Jan. 1943).

Temperature = -59.5°C.

Pressure = 120 mb.

$$\text{Molar volume}_{(\text{standard})} \times \frac{\text{Temperature}_{(\text{observed})}}{\text{Temperature}_{(\text{standard})}} \times \frac{\text{Pressure}_{(\text{standard})}}{\text{Pressure}_{(\text{observed})}}$$

= Molar volume at observed conditions.

$$359 \times \frac{273.2 - 59.5}{273.2} \times \frac{1013.3}{120} = 2370 \text{ ft.}^3$$

This is the mean pound molar volume at 15 km for Jan. 1943 over Lakehurst, N. J. This volume data was computed for levels up to 100,000 ft. over several stations and may be found in Appendix 3, plotted on the left hand side of figures 19 and 20.

B. Load-Diameter Maximum Altitude Relationships

Molar volume is related to buoyancy in the following fashion. Using 98% hydrogen of molecular weight, 2.11 lb./mol. and dry air of molecular weight 28.76 lb./mol., a buoyancy equal to the difference, 26.65 lb/mol. (See Table IV) is available whenever one pound molecular weight of hydrogen displaces one pound molecular weight of dry air under the same conditions of temperature and pressure.

TABLE IV

Buoyancy per Pound-Mol.

Helium (98%)	24.6 #/#mol, or 11.1 kg/#mol
Hydrogen (98%)	26.6#/#mol, or 12.1 kg/#mol

The number of mols in a balloon volume may be readily computed by dividing the air density, expressed in molar volume, at a given altitude into the balloon volume. The lift of the gas filling the balloon at any altitude is then equal to the number of mols multiplied by the buoyancy per mol. For example: To find the lift of the gas in a completely inflated (hydrogen filled) balloon of 20-foot diameter, at an altitude where the pound molar volume is 1000 ft.^{3} (This is equivalent to about 30,000 ft.):

Volume of a 20-foot diameter sphere = 4190 ft^3.

Number of mols in sphere at this altitude $= \frac{4190}{1000} = 4.19$ mols

Buoyancy = 4.19 mols x 26.65 #buoyancy/mol = 111.7 # lift given by the gas at 30,000 feet.

In one step, this becomes:

$$\text{Gross Lift/Balloon} = \frac{(\text{Balloon Volume}) \times (\text{Difference in molecular weights of air and lifting gas})}{\text{Molar Volume at a given altitude}}$$

Conversely, the maximum altitude to which a given size balloon will carry itself and a specified load can be determined, as a molar volume, which may be evaluated from a graph of altitude versus molar volume. Such graphs, computed as in Part A of this Section, are given in Figures 19 and 20, at the left hand edge.

Hydrogen and helium lifts were computed for various molar volumes for spheres of lifting gas with diameters from 7.5 to 75 feet. Figures 19 and 20 were plotted using the values computed. To use these figures to determine the maximum altitude of a balloon with a specified pay load, enter the table with required buoyancy (balloon weight plus payload). Go vertically to the diagonal line representing the balloon's size, and then read horizontally on the left hand edge, either the molar volume or the equivalent altitude over

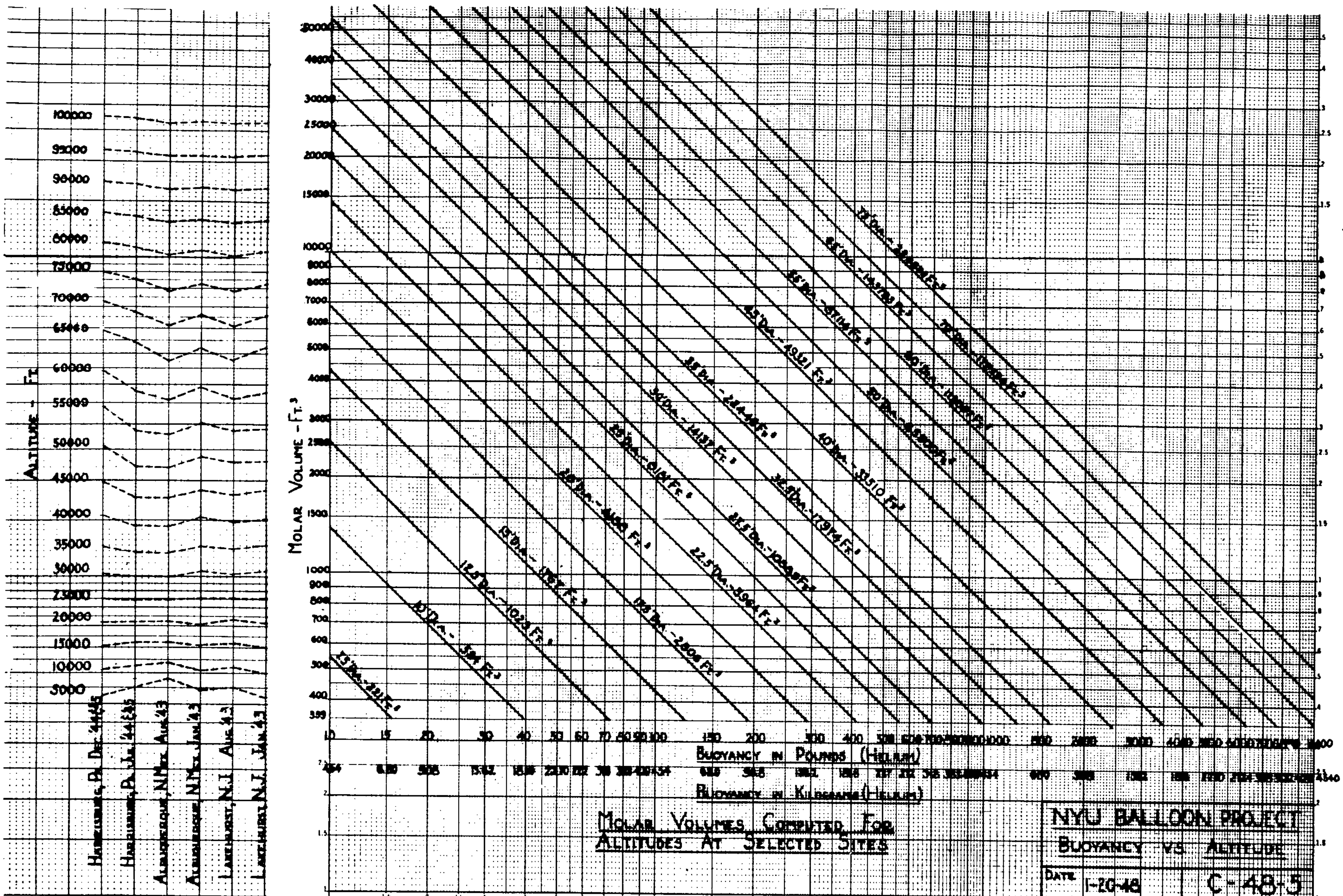
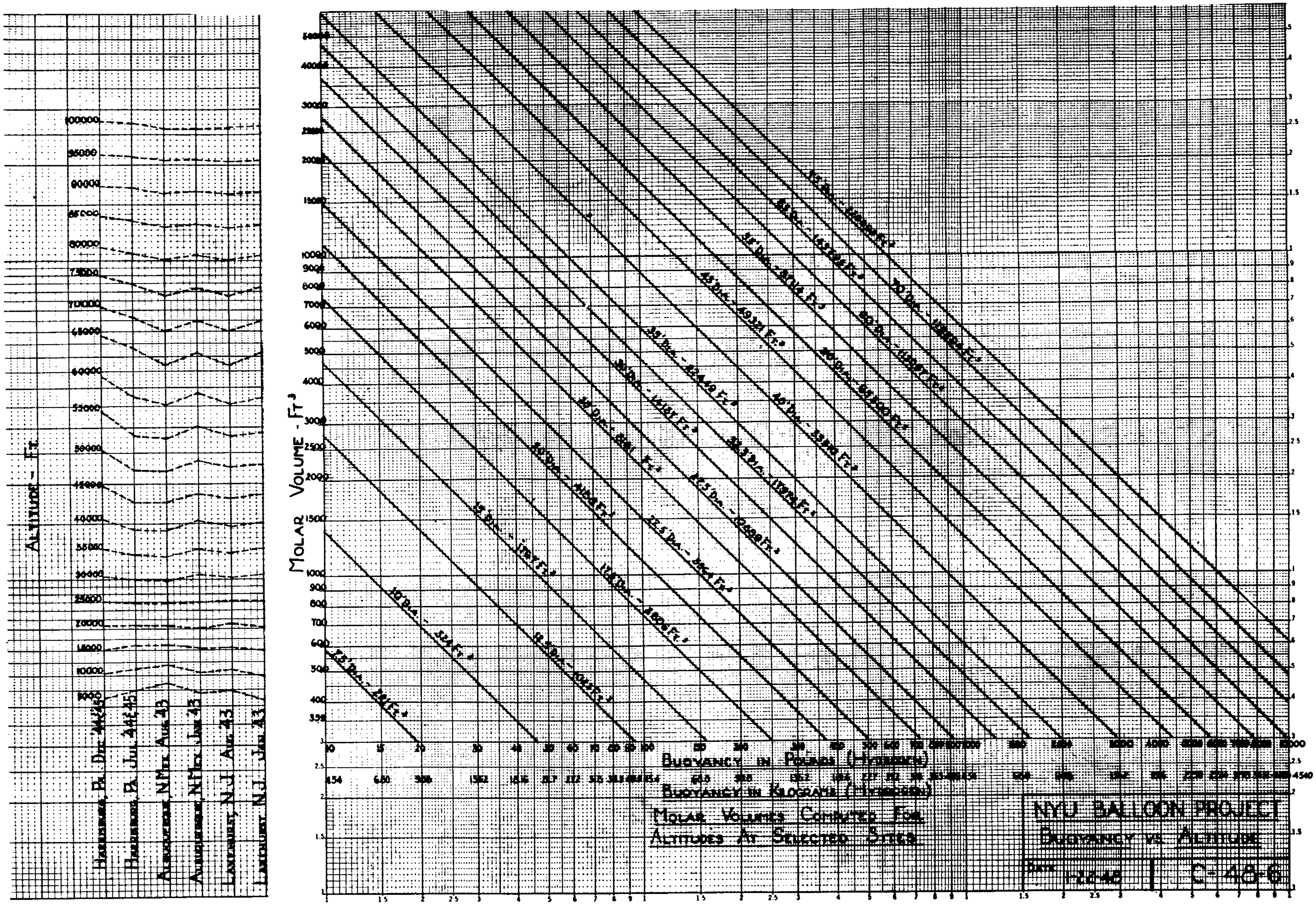

Altitude - Ft.
Molar Volume - Ft.^{3}
Buoyancy in Pounds (Helium)
Buoyancy in Kilograms (Helium)
Molar Volumes Computed for Altitudes at Selected Sites
NYU Balloon Project
Buoyancy vs Altitude
Date 1-20-48
C-48-5

FIG. 19



Altitude - Ft.
Molar Volume - Ft³
Buoyancy in Pounds (Hydrogen)
Buoyancy in Kilograms (Hydrogen)
Molar Volumes Computed For Altitudes At Selected Sites
NYU Balloon Project
Buoyancy vs. Altitude
Date 1-22-48
C-48-6

Fig. 20

sample stations. Figure 21 shows the calculated net lift of the General Mills balloons.

C. Balloon Diameter-Weight Relationships

To facilitate design discussions, charts have been drawn up relating the approximate weight of a balloon to its size and the unit weight of the balloon fabric. A ten percent increase is added to the weight over that determined from the surface area to account for seams and shroud lines. Figures 22 and 23 are these charts.

D. Rate of Rise

It is important that the rate of rise of a balloon be neither too fast nor too slow. For example, if a General Mills' 20-foot balloon rises faster than 900 feet per minute, there is danger of rupturing the balloon when pressure altitude is reached. On the other hand, if rates of rise under 400 feet per minute are chosen, since the free lift will be quite low, there is danger of: 1) a slight error in inflation resulting in the balloon's being unable to lift the equipment, or 2) with a wind much in excess of the rate of rise, the up-wind release failing due to the dragging of the equipment prior to its being lifted by the balloon.

To compute the free lift necessary for a given rate of rise, the equation developed by Korff[4] is used. This equation is:

$$V = 412 \frac{(F)^{\frac{1}{2}}}{(G)^{\frac{1}{3}}}$$

where F = free lift in grams

V = rate of rise in feet per minute

G = gross lift in grams

For our purposes, we wish to find F and have modified the equation to read:

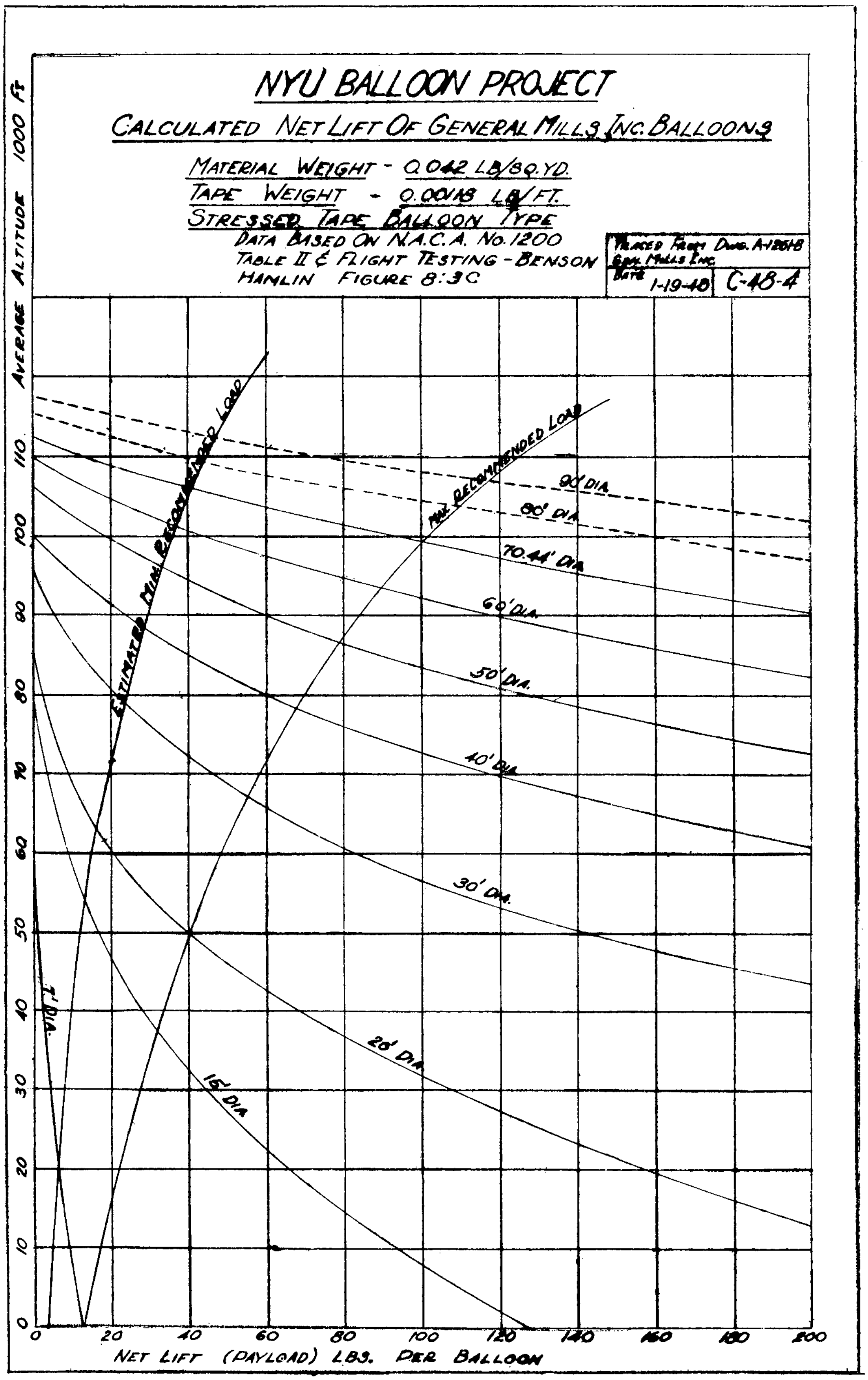
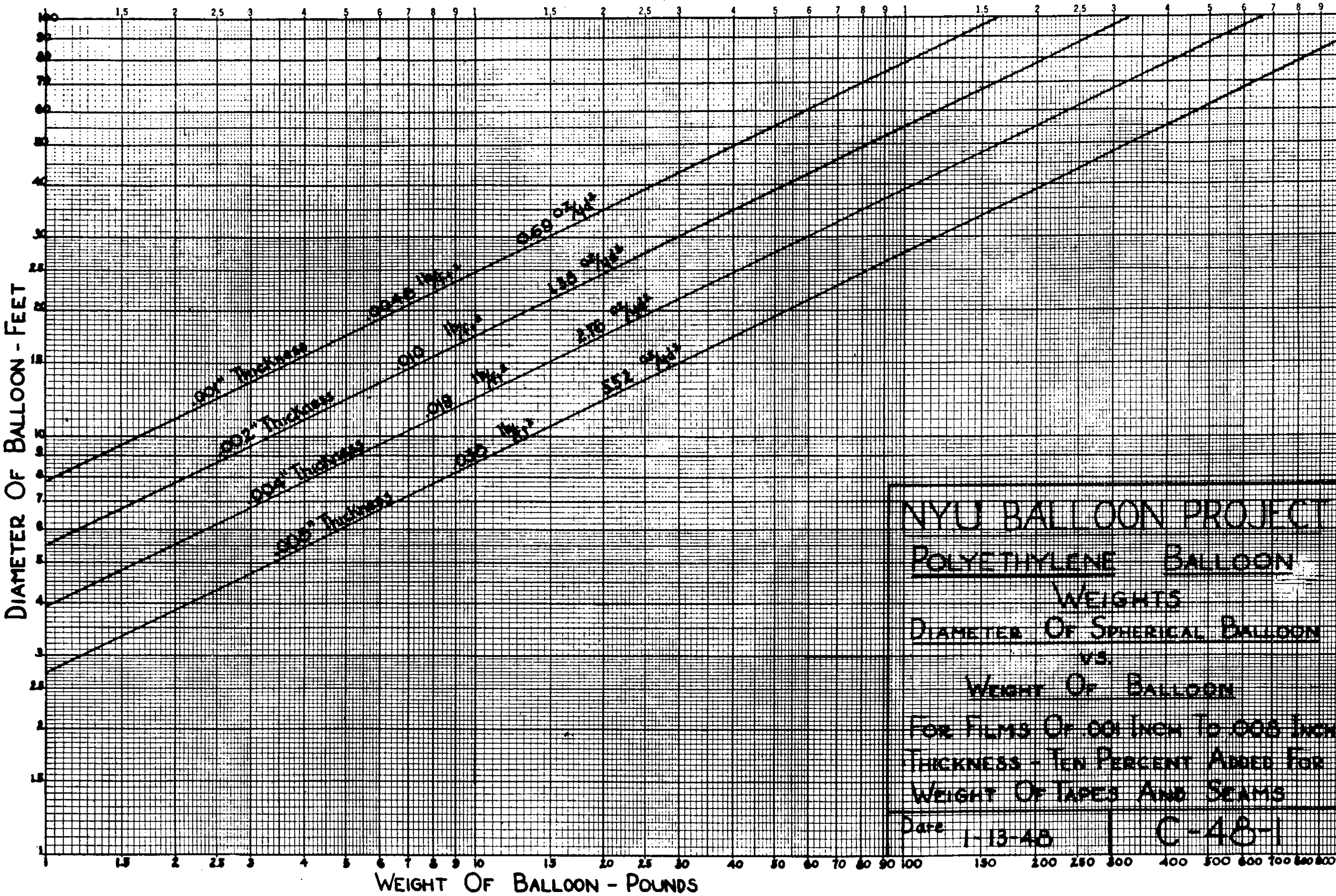
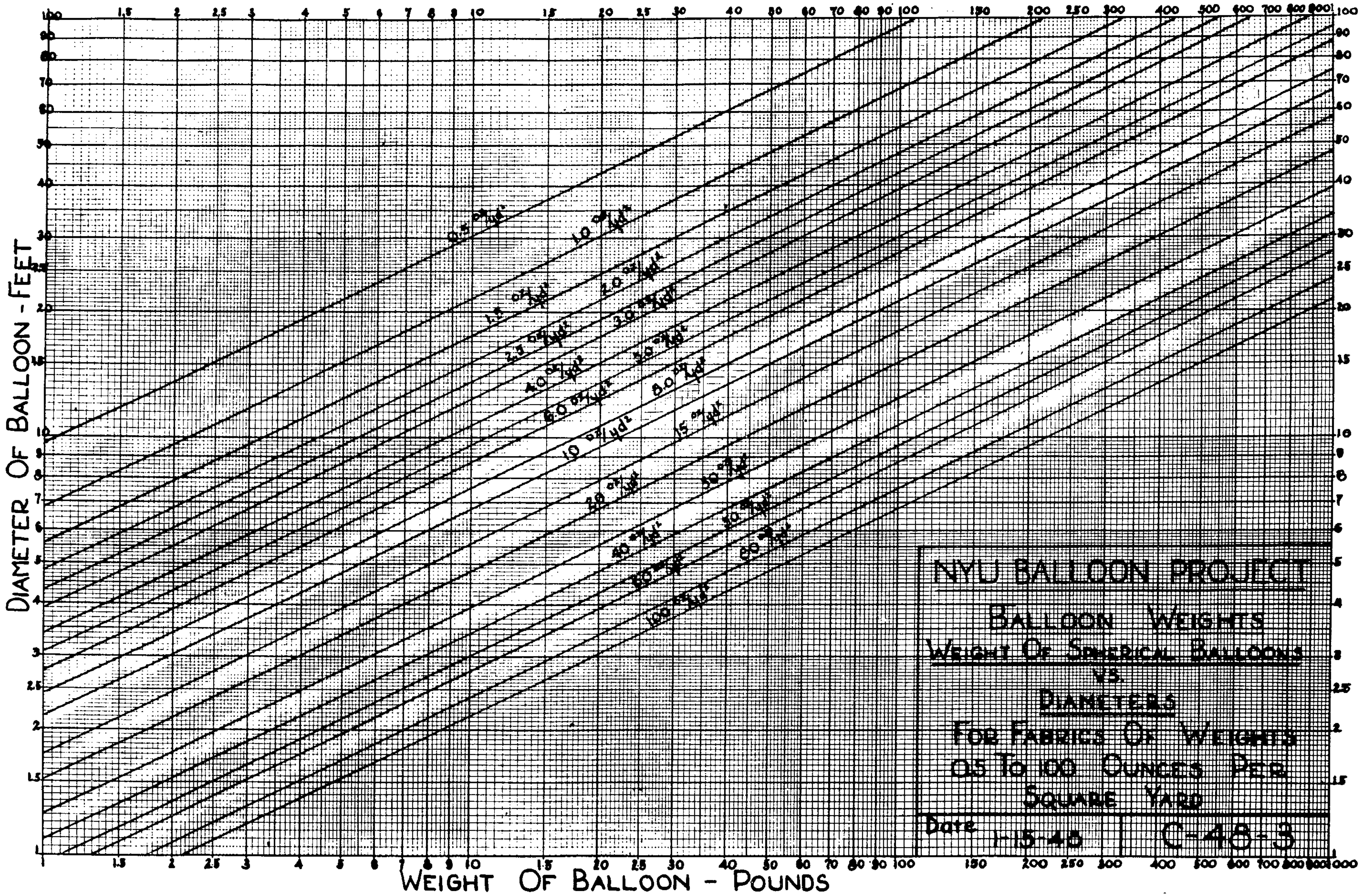

NYU BALLOON PROJECT
CALCULATED NET LIFT OF GENERAL MILLS INC. BALLOONS
MATERIAL WEIGHT - 0.042 LB/SQ.YD.
TAPE WEIGHT - 0.00118 LB/FT.
STRESSED TAPE BALLOON TYPE
DATA BASED ON N.A.C.A. No. 1200
TABLE II & FLIGHT TESTING - BENSON
HAMLIN FIGURE 8:3C
TRACED FROM DWG. A-12618
GEN. MILLS INC.
DATE 1-19-48
C-48-4
AVERAGE ALTITUDE 1000 FT
NET LIFT (PAYLOAD) LBS. PER BALLOON
ESTIMATED MIN. RECOMMENDED LOAD
MAX. RECOMMENDED LOAD
90' DIA.
80' DIA.
70.44' DIA.
60' DIA.
50' DIA.
40' DIA.
30' DIA.
20' DIA.
15' DIA.
7' DIA.
0
10
20
30
40
50
60
70
80
90
100
110
0
20
40
60
80
100
120
140
160
180
200

FIG. 21



NYU BALLOON PROJECT
POLYETHYLENE BALLOON WEIGHTS
DIAMETER OF SPHERICAL BALLOON
VS.
WEIGHT OF BALLOON
FOR FILMS OF .001 INCH TO .008 INCH THICKNESS - TEN PERCENT ADDED FOR WEIGHT OF TAPES AND SEAMS
Date 1-13-48
C-48-1
.001" Thickness
.002" Thickness
.004" Thickness
.008" Thickness
DIAMETER OF BALLOON - FEET
WEIGHT OF BALLOON - POUNDS

FIG 22



NYU BALLOON PROJECT
BALLOON WEIGHTS
WEIGHT OF SPHERICAL BALLOONS
VS.
DIAMETERS
FOR FABRICS OF WEIGHTS
0.5 TO 100 OUNCES PER
SQUARE YARD
Date 1-15-48
C-48-3
DIAMETER OF BALLOON - FEET
WEIGHT OF BALLOON - POUNDS
0.5 oz/yd²
1.0 oz/yd²
1.5 oz/yd²
2.0 oz/yd²
2.5 oz/yd²
3.0 oz/yd²
4.0 oz/yd²
5.0 oz/yd²
6.0 oz/yd²
8.0 oz/yd²
10 oz/yd²
15 oz/yd²
20 oz/yd²
30 oz/yd²
40 oz/yd²
50 oz/yd²
60 oz/yd²
80 oz/yd²
100 oz/yd²

F I G 23

$$F = \left(\frac{V}{412}\right)^2 \times \left(G\right)^{\frac{2}{3}} \qquad \text{(Approximate)}$$

where G = gross load

A chart, Figure 24, has beendrawn up, based on this equation, expressing free lift as a percentage of gross load, allowing the rate of rise to be approximately predetermined.

E. Ballast Requirements

The amount of ballast which must be dropped through the manual ballast valve to keep the balloon at its ceiling, can be approximately determined by the following measurements: a balloon of similar size and construction is inflated and its loss of lift with time is measured with correction for variation of temperature. This inflation is not complete, but is of the same magnitude as that of a balloon ready for release, approximately 14% of full inflation in the case of a General Mills balloon. The loss of lift per hour, multiplied by a factor representing the increase of the surface which results from total inflation, is thus obtained. This factor is the reciprocal of the fraction of inflation raised to the two-thirds power for a spherical balloon, and is approximately the same for the tear-drop shaped General Mills balloons.

Field experience has shown that ballast leak pre-set to slightly exceed the computed loss of lift is insufficient. A ballast leak of double the computed loss of lift has usually been adequate. It is believed that increased liquid viscosity and valve closure caused by the colder temperatures of the high atmosphere are responsible for the need for this higher ballast setting. An investigation into temperature effects on the ballast release systems has been started.

The amount of ballast which must be released at sunset to compensate for the loss of superheat, may be computed as follows:

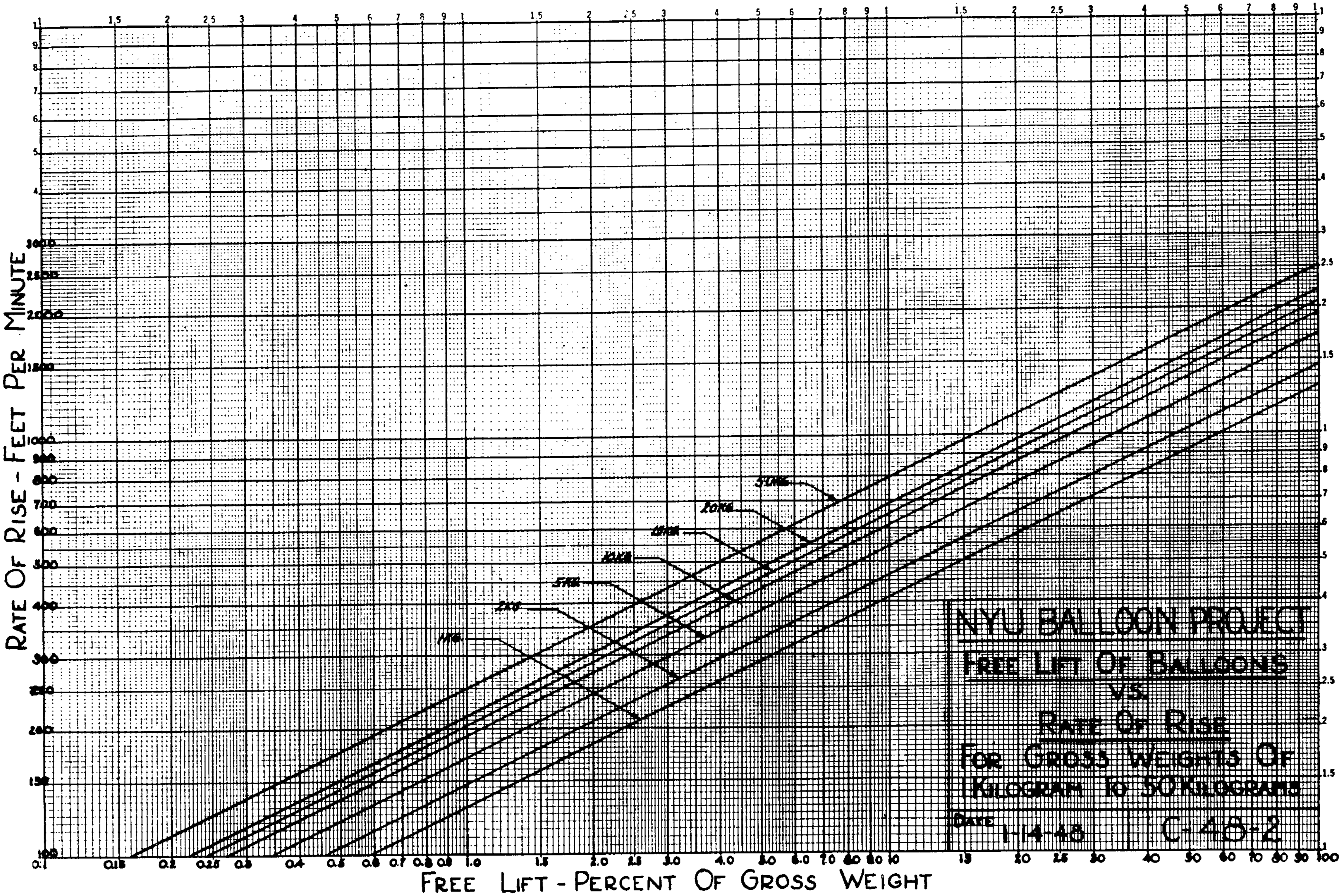

NYU BALLOON PROJECT
FREE LIFT OF BALLOONS
VS.
RATE OF RISE
FOR GROSS WEIGHTS OF
1 KILOGRAM TO 50 KILOGRAMS
DATE 1-14-48
C-48-2
RATE OF RISE - FEET PER MINUTE
FREE LIFT - PERCENT OF GROSS WEIGHT
1KG
2KG
5KG
10KG
15KG
20KG
50KG

FIG 24

$$\Delta G = G \times \frac{\Delta T}{T} \times (1 + K)\ K$$

where ΔG = loss of lift

G = gross load (balloon weight plus equipment load)

ΔT = mean temperature difference in lifting gas before and after sunset

T = free air temperature

K = specific gravity of lifting gas, relative to air

The specific gravity of 98% helium, diluted with air, and with respect to air, is 0.157. It may be noted that with a lower specific gravity of a gas, lower ballast corrections are required. Hydrogen, for example, requires half the ballast which helium requires for the same temperature differential. At high altitudes, a difference of 40°C may be expected in the temperature of the lifting helium from day to night. This would correspond to a loss of lift at sunset, on a General Mills 20-foot balloon, of about 550 grams.

F. <u>Internal Pressure</u>

The maximum internal pressure which can be held within a spherical container is given by Timoshenko[8]:

$$P = \frac{2S_u \times t}{r}$$

where S_u is the ultimate strength of the material in tension, t is thickness of the material and r is the radius of the spherical shape. Applying this equation to a polyethylene film, such as used in the General Mills 20-foot balloons, S_u at room temperature = 1900 psi., t = 0.001", and r = 10 ft., giving the maximum pressure, P = 0.032 psi. This pressure is equivalent to about 1.1 inches of water, or 2.5 mb. This small bursting pressure necessitates proper inflation and load values to prevent the balloon's bursting at pressure altitude.

A series of forms which have been used to facilitate computations have been drawn up. They are included in Appendix 3, together with a table of altitudes based on the N.A.C.A. Standard Atmosphere[6], and other useful reference tables.

TABLE V

Glossary

Equipment load: Weight of all equipment, rigging, and ballast hung from the balloon shrouds not including balloon or its integral parts.

Gross load: Load on the gas at release (Balloon plus equipment load weight).

Free lift: Net lift of the balloon with the equipment load attached.

Gross lift: Lift of all of the gas in the balloon at release (Equals weight of the balloon, equipment load plus the free lift).

Balloon inflation: Gas inflation to be given the balloon in terms of initial lift of the balloon (equals weight of equipment load plus free lift plus allowance for gas losses before launching).

Floor: The locus of altitudes at which a balloon will float when lift losses are exactly compensated for on a demand basis by ballast dropping. In practice, this is determined by the operation of the automatic ballast release and is some altitude below the ceiling.

Ceiling: The locus of pressure altitudes at which a non-extensible balloon will float when gas losses are slightly over-compensated for by ballast losses.

Pressure Altitude: The altitude at which a non-extensible balloon becomes fully inflated.

Pressure Height: The height above mean sea level as determined from pressure measurements used in this work with the N.A.C.A. Standard Atmosphere.

Section 4. Flight Techniques

The general techniques of preparing and launching controlled altitude balloons are patterned after those of the smaller radiosonde balloons. The treatment of large, manned balloons has been studied, however, and information of considerable value has been gleaned; as from the National Geographic Society reports of the flights of Explorer I and Explorer II[11,12], and from the book by Upson and Chandler[15]. From these and other studies[13, 14], and from original experimentation with General Mills advice, a satisfactory technique of handling controlled-altitude balloons has been developed.

A. Inflation

The lifting gas used for these large balloons has been helium. The choice of gas was made on safety considerations. Hydrogen, however, has several advantages over helium. It will lift 9% more than helium and, due to its lower specific gravity, requires but 50% of the ballast release that helium requires to correct for disappearance of superheat at sunset. Helium, on the other hand, leaks and diffuses at a rate but 70% that of hydrogen. However, for long flights, hydrogen would probably have more over-all economy of ballast.

Inflation has been made through a low-pressure, diffusing manifold, feeding from a number of helium tanks simultaneously to the balloon. The smaller balloons have been inflated inside a hangar, permitting very exact weigh-off of the balloon's free lift, thus predetermining the rate of rise fairly well. The plastic balloons larger than 15 feet in diameter have generally been inflated out-of-doors, as no hangar large enough for interior inflation has been available.

The 20-foot General Mills balloons are inflated through a tube in such a fashion that the gas collects in a bubble at the top of the balloon. The tube is inserted by the manufacturer and is shown in Figure 5. If this bubble is restricted, the wind cannot catch and make a sail of it. (See figure 25 for the sail effect.) The actual technique of inflation is as follows:

> In actual inflation the balloon is spread out on a ground cloth which covers the launching table and a balance. The balloon is arranged so the upper 18 feet projects beyond the balance. Two heavy (80#) elliptical shot bags (see Figure 26) are covered with polyethylene and placed on top of the balloon on either side of the inflation tube. The platform is then made to balance. The lower end of the balloon is weighed and then stretched out again down wind, held down with sand bags and polyethylene strips. A weight equal to the weight of the lower half of the balloon, plus the equipment weight and the desired free lift is placed on the balance. Inflation is started, taking care to get all twists out of the inflation tube before allowing full gas flow. When the balance beam falls, inflation is complete (care must be exercised to guard against underinflation due to wind moving the balloon on the balance). The inflation tube is carefully removed, and the helium truck is moved clear. All personnel are now positioned for release.

B. Release

During the early portion of the experimental period, flights of meteorological balloons in clusters were launched. The first flights were made with balloons hitched one above another along a single strong load line.

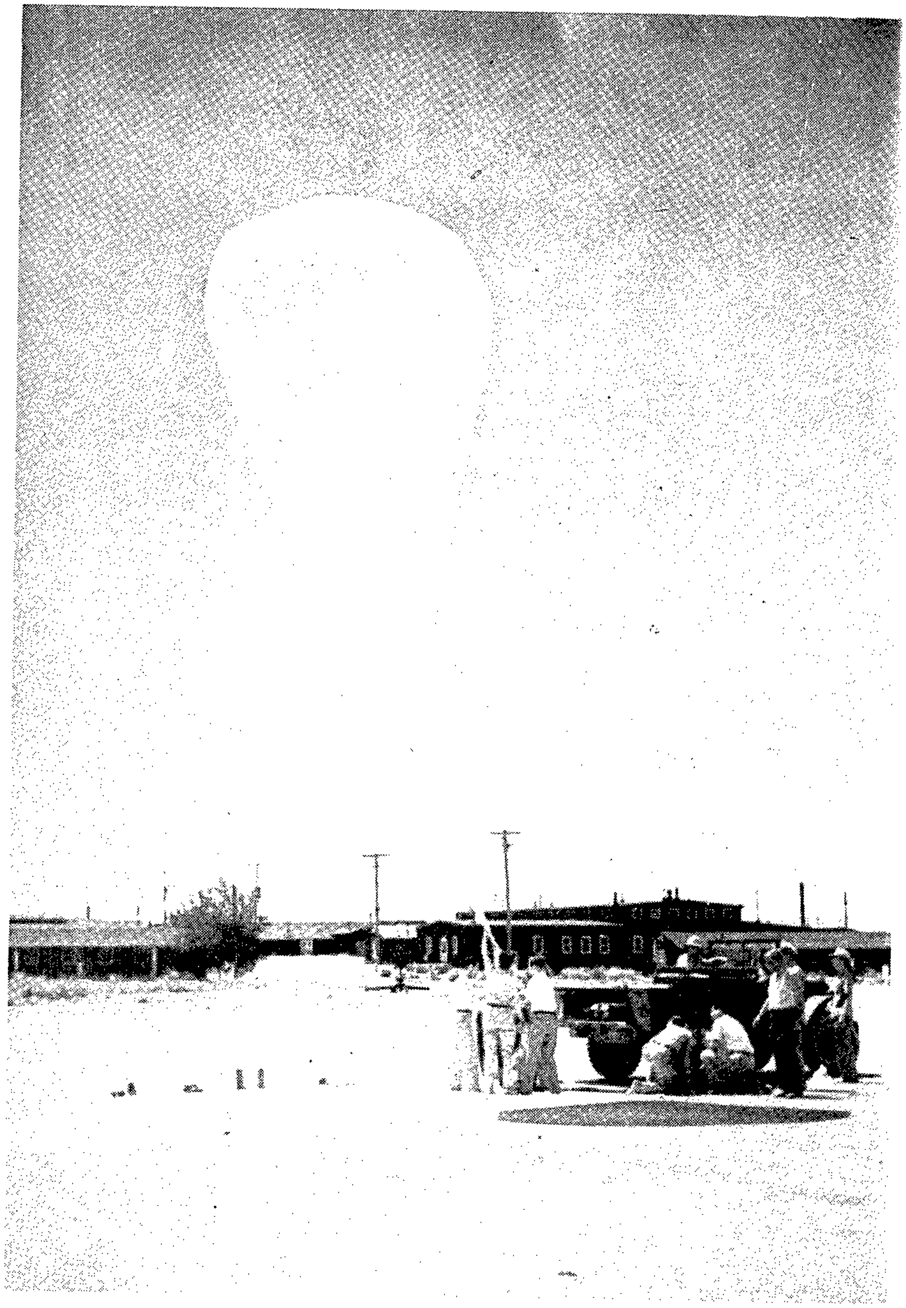
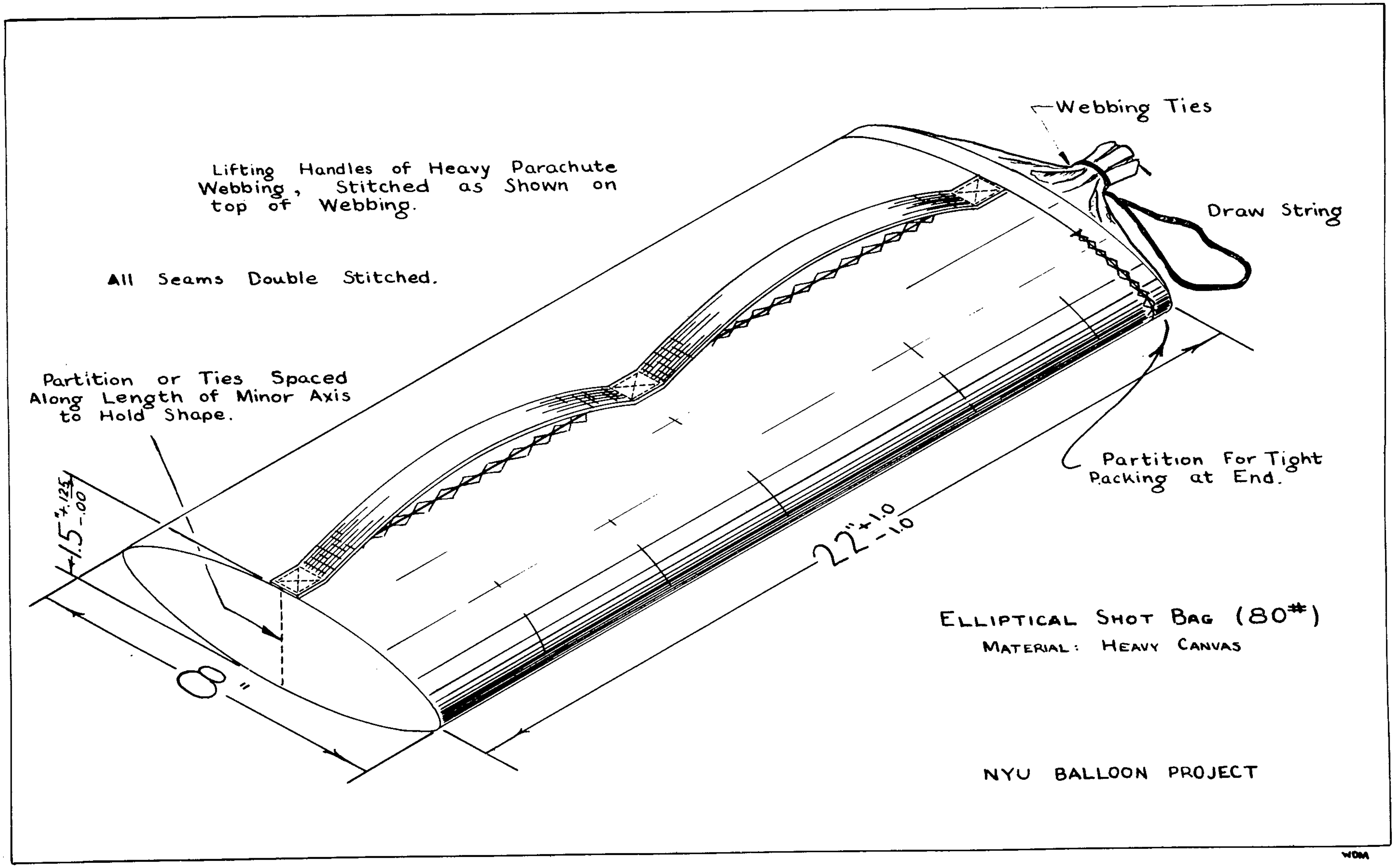


Figure 25
General Mills 20 foot balloon
billowing in a five knot wind.



Webbing Ties
Lifting Handles of Heavy Parachute Webbing, Stitched as Shown on top of Webbing.
Draw String
All Seams Double Stitched.
Partition or Ties Spaced Along Length of Minor Axis to Hold Shape.
Partition For Tight Packing at End.
1.5" +.125 -.00
22" +1.0 -1.0
8"
ELLIPTICAL SHOT BAG (80#)
MATERIAL: HEAVY CANVAS
NYU BALLOON PROJECT
WDM

FIG. 26

With these and subsequent rigging lines the following technique was used: on all lines a strength test was made and a safety factor of at least ten to one was demanded. Most of the lines used are of braided or woven nylon, chosen for its low weight-strength ratio. To facilitate handling of the line segments each length is prepared with a small hook on either end. The knots employed are double carrick bends.

The total length of the early trains reached as much as eight hundred feet, making them extremely difficult to release. A system of restraining the load line was evolved with two winches paying out restraining lines while balloons and equipment were added to the load line. In this way the pull of the balloons themselves and the much greater strain caused by even light winds was held by winches. When the final piece of equipment was clear of the ground (or when the entire flight line was under tension with the lowest element being held back) a gunpowder squib was electrically fired to sever the restraining lines near the bottom of the balloon. Figure 27 shows the aluminum "cannon" holding the gunpowder, the two winch lines and a light line used to pull the restraining lines away from the load line after firing. The load line has not yet been attached in Figure 27, but will be fixed just above the "cannon".

When the restraining line is severed, there is danger of a pendulum swing of the train causing the lower components to be dashed into the ground. To avoid this action, the lowest piece of equipment is usually held by a member of the crew on the back of a truck. By driving downwind faster than the surface wind speed, the pull of the balloon can be resolved into only a vertical component and the equipment may be safely released when the truck gets under the balloon.

With later plastic cell flights, this method of launching was also used in cases of light wind. When winds of about 5 knots are encountered,

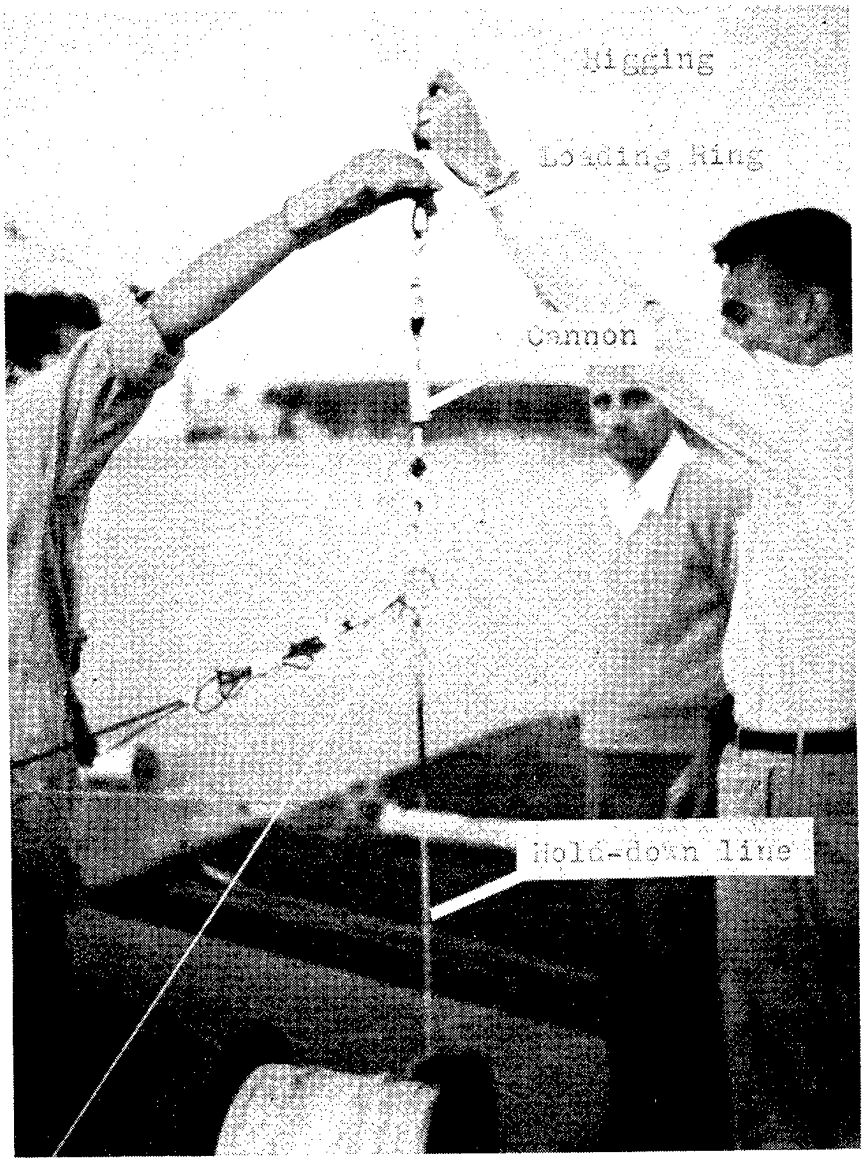


Figure 27
Aluminum "cannon" and launching lines used to restrain balloon while load is being attached.

the total strain on rigging lines and even on the balloon itself becomes excessive. With the thin polyethylene film of the General Mills' balloons, such a wind force causes the balloon first to billow, sail-like, as in Figure 25, then to tear.

To eliminate surface failures on days when the wind is not calm, the following release technique is employed: The equipment train is laid out parallel to the wind direction, with the balloon in the lee of a large building and the other components stretched out downwind. The central portion of the balloon rests on a platform balance and the lower portion rests on a sloping eleven-foot table whose top is level with the platform and whose bottom rests upon the ground. The upper portion of the balloon usually lies on another table, level with the platform. Except for this upper portion, the balloon is held down on the scales and sloping table by bags of sand and lead shot. In addition, one sand bag is fastened to the lead thimble of the balloon by a short line which is kept taut during inflation. This layout is shown in Figure 28.

When the balloon is inflated, it is held down at the weighing-off scales by the shot bags. Personnel required for the launching consist of two men at the hold-down shot bags (who lift the bags at the release signal), one man near the large sand bag (who cuts the line to the load thimble when the balloon rises above him), one man at each piece of sensitive equipment on the train (to support and protect the equipment until it is airborne), one man at the lower end of the hold down line (who fires the cannon severing the last line when the gear is all safely lifted).

If each operation is performed when the balloon is directly overhead and if the train has been accurately laid out downwind, the entire train is sent off with a minimum of oscillation of the load. Figure 29 shows successive positions of the balloon and gear during release.

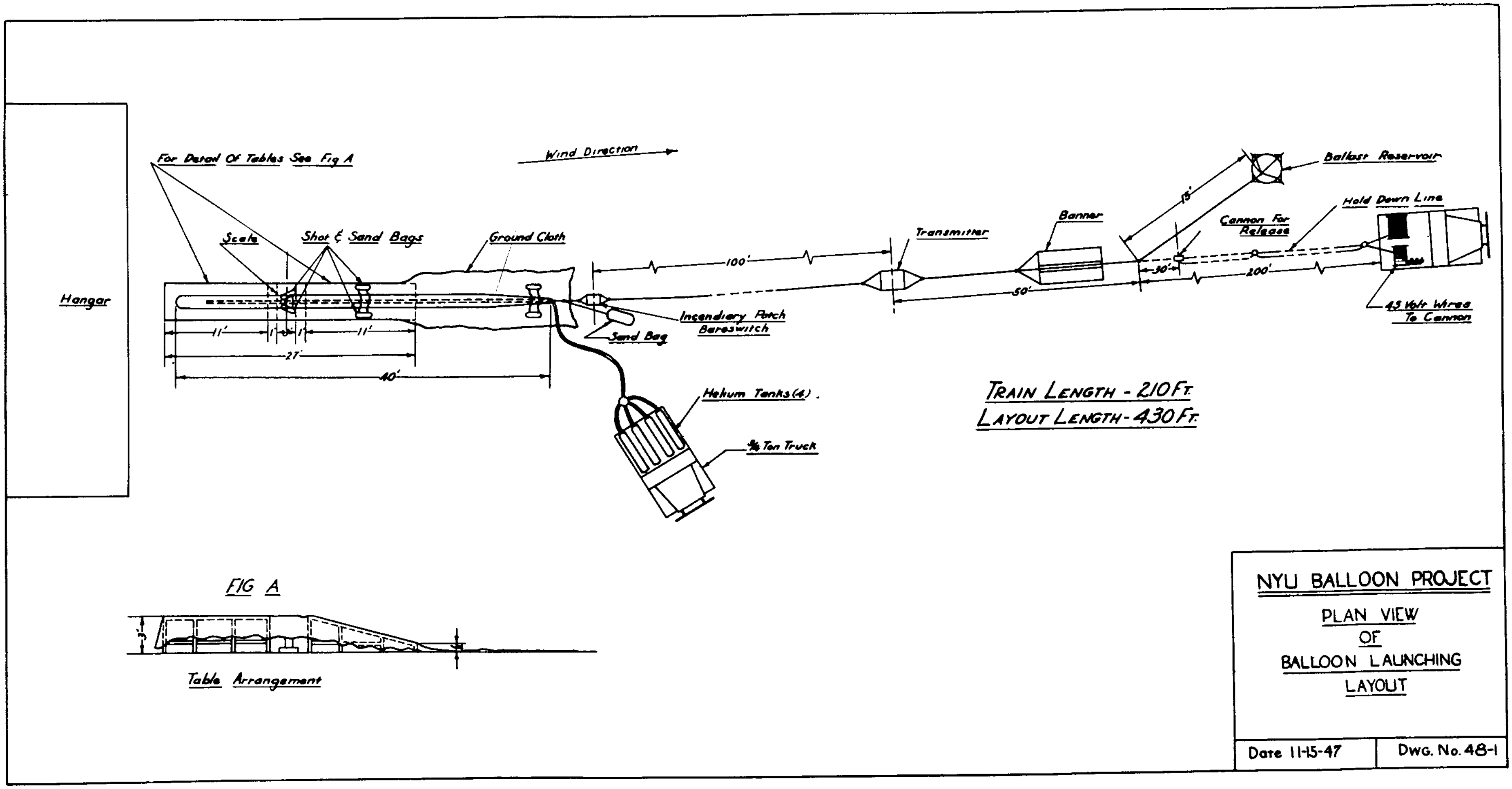

For Detail Of Tables See Fig A
Wind Direction
Hangar
Scale
Shot & Sand Bags
Ground Cloth
11'
1'
1'
11'
27'
40'
100'
Transmitter
Banner
15'
Ballast Reservoir
Cannon For Release
Hold Down Line
30'
200'
50'
43 Volt Wires To Cannon
Incendiary Patch Baroswitch
Sand Bag
Helium Tanks (4).
¾ Ton Truck
TRAIN LENGTH - 210 FT.
LAYOUT LENGTH - 430 FT.
FIG A
3'
Table Arrangement
NYU BALLOON PROJECT
PLAN VIEW
OF
BALLOON LAUNCHING
LAYOUT
Date 11-15-47
Dwg. No. 48-1

FIG 28

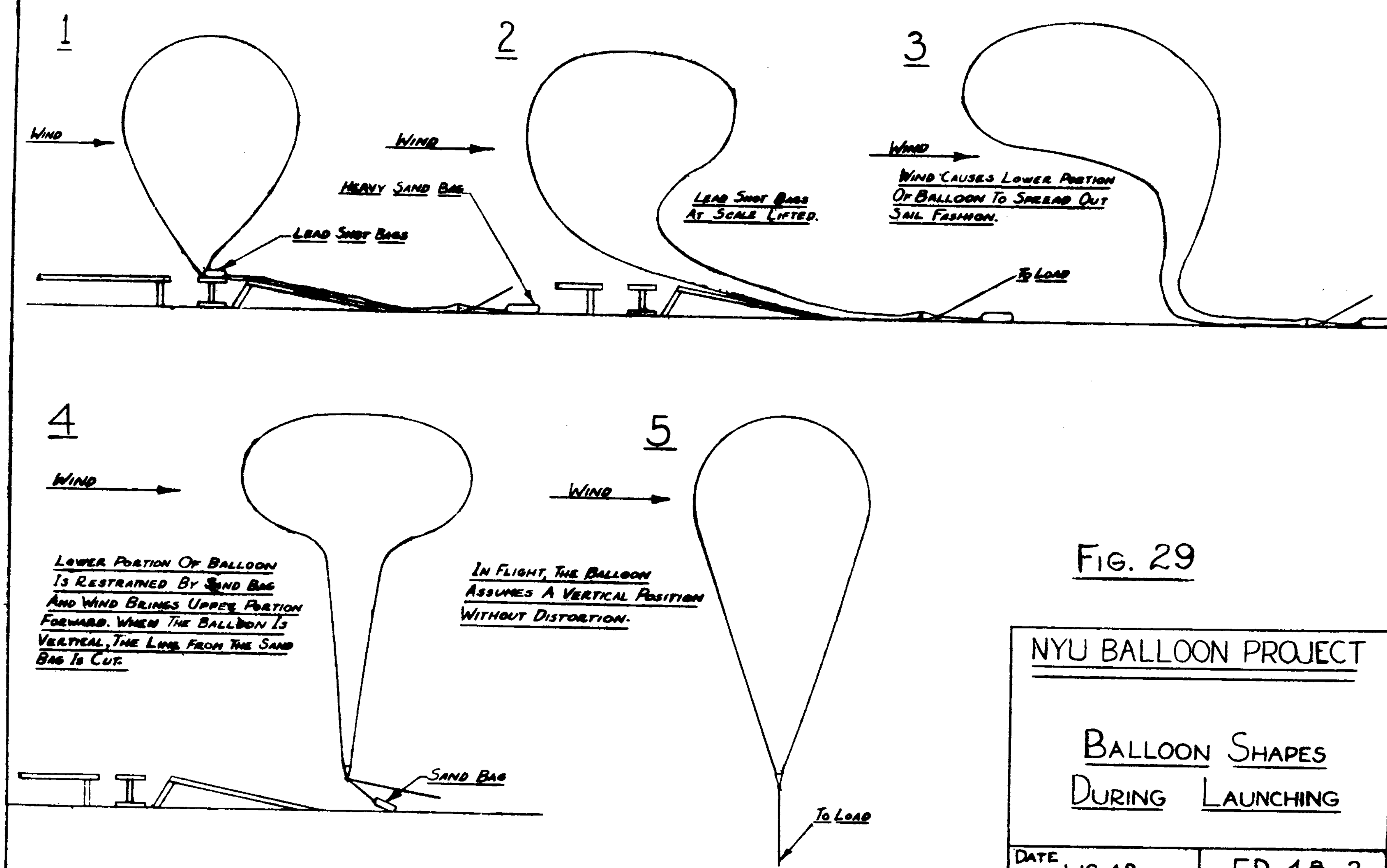


Fig. 29

NYU BALLOON PROJECT	
BALLOON SHAPES DURING LAUNCHING	
DATE 1-16-48	ED-48-3

This method of release is a development of the upwind release used in radiosonde flights in the U.S. Weather Bureau, with refinements first used by General Mills Aeronautical Research Laboratories and necessitated by the larger balloon size and the number of components on each flight.

Using this method, successful releases were made at Alamogordo in winds of 20 miles per hour with gusts up to 30 miles per hour.

C. Recovery

Much additional information on the behavior of the train components can be gained if they are recovered. Two methods of recovery are employed: 1) reward tags and 2) recovery by the balloon crew tracking the flight.

Reward tags attached to several components have encouraged the finders to protect the equipment and report its location. The tag and associated questionnaire are included in Appendix 3. Total recovery of flights to date is about 60% of those released.

When the location of the balloon is known by visual observation from an airplane, or the landing area is indicated by direction-finding gear, recovery is attempted by truck by the balloon crew or the crew at one of the downwind stations. Several successful recoveries have been made of flights of relatively short range. It was found in earlier attempts that the balloon equipment was a difficult target both in the air and on the ground. Consequently a colored cheesecloth banner (6 by 12 ft., stiffened top and bottom) was added to the train. It also is a convenient marker for theodolite stadia measurements. A banner may be seen in Figure 30. White banners seem to be the most generally useful.

Section 5. Flight Summary

A summary of pertinent information on all flights made to date is included in Appendix 1 as table VII. Also shown there are flight train

Figure 30
General Mills 20 foot balloon
in flight, showing banner and other
flight train components.

diagrams, time-height curves, trajectories and photographs of significant flights, grouped by flight numbers. The flight numbering system has been revised since its inception and now only those flights in which an attempt was made to control the altitude of the balloon are included in the summary. Excluded are flights made to test special gear and launchings which were not successful.

Flights A, B, 1, 5, 6 and 7 all made use of meteorological balloons in various arrangements and combinations. Each flight included one or more "lifting balloons" which were to be released from the train when the desired altitude was reached, the other balloons then theoretically supporting the load at the constant altitude.

Figures 31 and 36 show the two methods used to group the balloons in clusters. Figure 31 shows the linear array borrowed from cosmic ray flight techniques; figure 36 shows the modified "Helios Cluster" in which lines from the balloons are joined at a central ring at the top of the load line.

The Helios cluster was by far the easier to handle because of the simpler rigging and the reduced launching strains.

Flight 7 was the only one of this group in which anything approaching a controlled altitude was attained. The previous flights failed to level off when the lifting balloons broke loose. In flights 1, 5 and 6, where ballast dropping devices were included, the ballast either did not drop, or the dropping did not have the desired effect. In flight 7, however, the cluster rose till the lifters were cut off, descended until sufficient ballast was dropped to cause the cluster to rise to a still higher altitude. There several balloons burst, resulting in a final descent. The time-height curve for this flight is shown as figure 38.

This flight pattern represents the best approximation to constant level flight that we have obtained with meteorological clusters.

Flights 8 and 11 each employed more than one polyethylene balloon in an attempt to reach higher altitude than possible with the single balloons then available. Figure 39, 40, 41, 44 and 45 show the type and arrangement of balloons and their flight behavior. In both flights, the maximum altitude was not high enough to cause activation of the automatic ballast valve. Consequently, there was no compensation for diffusion other than the steady leakage of ballast through the imperfect seating of the valve. In flight 8, after one hour, this leak was not sufficient to maintain a constant altitude, so the flight terminated. However, in flight 11, constant altitude was maintained at 16,000 ft. $\pm$ 1500 feet for 7 hours until all of the ballast was expended.

Flight 10, in contrast to flights 8 and 11, did reach an altitude at which the automatic ballast control was actuated, resulting in a flight of perhaps more than 26 hours. Although the maximum altitude reached by this heavy spherical cell was 15,000 feet, the ballast control was effective at a level of 9000 feet. The expected difference between activation level and operation level was probably exceeded because of the temperature effect of the air entrapped in the pressure capsule.

Figure 42 shows the train, and figure 43 shows the time-altitude curve for the 512 minutes of radiosonde data.

The oscillations around 9000 feet during the last two hours of data may be attributed to the changing buoyancy of the balloon as cloud masses intermittently shielded it from the sun's rays. An unconfirmed report was received to the effect that this balloon was still floating 26 hours later over Pueblo, Colorado.

Flight 12 was designed to overcome the difficulties encountered in flights 8 and 11, and, by the use of a thin tear-drop balloon (General Mills balloon) to carry the load to a higher altitude than flight 10. To guarantee a predetermined constant ballast flow, the manual ballast valve was added to the flight train. The minimum pressure switch replaced the fixed pressure switch to activate the automatic ballast valve, whether or not a predetermined activation altitude was reached. Figure 46 shows the train; figure 47 shows the time-altitude curve, which exhibits a marked departure from the ideal. The minimum pressure switch failed to operate or operated near surface pressure, effectively preventing the operation of the automatic ballast valve. The manual ballast valve did not provide sufficient flow to prevent the gradual descent of the balloon. Finally, the heavy load necessitated almost complete inflation of the balloon at the surface. This distention permitted continual mixing of air through the open bottom of the balloon. Instead of reaching the pre-calculated 38,000 feet maximum altitude, this flight had a peak of 14,000 feet from which it slowly descended. Since the blowout patch was set to act upon descent to 20,000 feet, it also failed to operate.

Five of the succeeding flights (nos. 13, 14, 15, 16 and 20) had as a prime objective the development of a satisfactory appendix to overcome the loss of buoyancy due to mixing during launching and ascent. The types considered have been discussed in Section II, Part A of this report and the (two foot) appendix stiffened with battens, which was finally evolved, is shown in figure 5. Figures 48, 49 and 50 show the time-altitude curves for these flights. Either short flight or limited radio reception curtailed the trajectory data.

In flight 19, the danger to personnel of the blowout patch was dramatically demonstrated by its firing 30 seconds after release. Launching shocks caused the baroswitch pen-arm to fall off its shelf, completing contact prematurely. In later flights, a time delay switch was placed in series with the baroswitch to prevent a recurrence of this action.

Flights 21, 22, 24, 26 and 27, although carrying altitude control devices, were flown to test gear for associated projects. Either no pressure reporting gear was carried or the data from modified gear proved unreliable. Hence few performance data charts are presented.

Flight 21, using a late-model General Mills 20 foot thin cell and an automatic ballast valve, is known to have lasted for ten hours, descending at Marietta, Oklahoma.

Flight 22, included an earlier model General Mills balloon with a high rate of gas leakage, and an automatic ballast valve. The ballast control kept the balloon aloft, but for only six hours.

Flight 24, including an automatic ballast valve, is believed to have maintained constant level, $\pm$ 1,000 feet, for 122 minutes. It stayed aloft for at least $3\frac{1}{2}$ hours, when transmission ceased. The time-altitude curve is shown in figure 51.

Flignt 27 employed a fixed rate of leak rather than an automatic ballast valve. The manual control did not provide sufficient ballast flow, accounting for the time-altitude curve shown in figure 52.

Flights 29 through 37 and flight 39 were undertaken to test the downwind launching procedure, to try for higher constant level altitudes, and to determine the feasibility of using the General Mills thin cells for frequent service flights. Flights 37 and 39 burst early. The former was released during a rainstorm and balloon failure occured at the seams.

Flight 29, with a manual ballast valve, was released just before sunset on 22 November. It was observed descending 50 miles north of Toronto, Ontario, Canada, 14 hours later. The average wind was 130 mph. Radio receiption was for 69 minutes.

Of the other recent flights, satisfactory radio performance was enjoyed only on flight 36. Before any more flights are made, a better transmitter and battery pack will be needed. Even on this flight the signal was lost after 135 minutes, due to excessive range. The last plotted position was northeast of Tucumcari, N.M. This flight was recovered from Burlington, Iowa.

Time-height curves of this series are included in figures 53, 54 and 55. Despite the limited data, some results can be determined. For example, flight 32 is believed to have floated for at least 70 minutes within 1,000 feet of a constant level above 40,000 feet MSL.

Flight 35 also exhibited 32 minutes of constant-level flight before the radio signal was lost. From the remarkable distances that some of the others traveled (See flight summary Table VI, Appendix I) it is almost certain that they floated for long periods.

These flights included a simple-filter manual ballast valve assembly (Figure 9) designed to reduce equipment weight and cost. The performance of this equipment justifies its continued use for relatively short flights.

Considerable difficulty was experienced with the type of filter used. Experiments are now being conducted to improve the filter.

Because of limited data received from earlier flights, modified Fergusson meteorographs were added to the equipment train on flights 33, 35 and 39. As of January 1, 1948 none of these instruments have been recovered.

Flight 17, using a fifteen-foot balloon of .004 Polyethylene is worthy of special consideration. The thickness of this type of cell eliminates much of the problem of appendix design since more internal pressure can be withstood. Despite this factor, and the low permeability of the fabric, balloons of this type are too heavy and costly to be used for high altitude flights.

The trajectory and time-altitude curve of this flight are shown in figure 56 and 57. This controlled-altitude flight demonstrates that the automatic ballast valve combined with a fixed leak, will successfully maintain constant altitude through a sunset. The balloon floated at 29,000 feet ± 500 feet for at least three hours, after which the excessive range prevented further radio reception. Here again the necessity of a barograph was demonstrated as the balloon was recovered from Pratt, Kansas, 530 miles away. Two flights, 23 and 38, were made using the shrouded Dewey and Almy J-2000 Neoprene balloon. Both of these flights were failures. Flight 23 (see figure 48) attained a maximum altitude at 50,700 feet and began to descend immediately. Flight 38 (see figure 55) was observed from a B-25, and the balloon was seen to burst within the shroud.

Section 6. Current Objectives

In order to meet the requirements for future flights, improvement must be made in three phases:

1. Performance data for too many flights have been either uncertain or of too short duration. Before more flights are undertaken, altitude-measuring instruments must be improved and increased. To this end, four specific improvements are being undertaken:
    - A. To supplement the pressure data received by radio, a lightweight barograph will be added to those flight trains in the future when flights of more than a few hours' duration are attempted.

B. The improvement of radio transmitter gear; it is planned to utilize the three megacycle transmitter developed in the Electrical Engineering Laboratories at New York University. In previous tests, this has provided clearer reception and a longer range for comparable weight than either the 72 megacycle or 397 megacycle units previously used. To provide direction finding, 397 megacycle carrier signal will also be transmitted which will be tracked by SCR-658 sets. It is also hoped that a better light weight battery pack can be developed for airborne use.

C. The Olland cycle time-interval method of presssure measuring and data presentation is being adapted, with the following advantages anticipated:

(1) The direct interpretation of pressure data in terms of the time interval eliminates the ambiguities inherent in counting pressure contacts in the Diamond-Hinman system. Used in conjunction with the Brush recorder operating at medium speed, and with four turns on a helix rotating once a minute, the pressure readability of this system will be better than one millibar.

(2) Under noisy conditions the recorded data obtained with this system will be more readable than the audio signal now being employed. When only pressure data is being transmitted, this system can be more economical of power than is a system of modulated audio frequencies.

(3) In cases where data other than pressure is also to be transmitted on the same radio channel, the pressure

signals may be arranged so as to consume a very small portion of transmission time.

D. The duration of radio reception and of positioning data may be greatly extended by appropriately equipped aircraft. It is intended to utilize a B-17 with top-mounted radar to search above the plane for tracking. Depending upon the noise-level encountered, it may be possible to acquire pressure data with a receiver in the plane. It may be necessary to provide at least two aircraft for continuous reception over long periods.

2. It is very desirable that the simplified light-weight ballast control system for flights of less than 24 hours' duration be perfected. The elaborate ballast assembly with the automatic ballast valve will not be needed for the many contemplated flights which will be made with a useful life of less than eight hours. A lower-capacity reservoir with manual ballast valve and filter provides a light-weight, inexpensive unit. Tests are now being conducted to find the best design for these components.

3. In order to float a balloon at a pre-selected maximum altitude it is necessary to supplement the variation-of-ballast with a new height control system.

A. With a given balloon, and given total load, it is possible to forecast the maximum height. (See Section III for the computation.) If various maximum heights are desired, this maximum height may be varied by varying the total load, or varying the bouyancy of the balloon through variation in balloon volume.

The method used heretofore is variation of balloon load through changes in the amount of ballast used. However, there are upper and lower limits on the amount of ballast that can be used, due to the strength limitations of the fabric. Also, the "height sensitivity"; that is, the ratio of change in altitude to change in load, is not great enough to provide suitable choice of heights.

B. Another attack is to effect a change of volume by making openings below the equator of the balloon. The volume of gas contained in the balloon envelope is then obviously limited.

C. If this method of height control proves to be unsatisfactory, still other control mechanisms will be sought.

The three objectives, with their indicated subdivisions, will be pursued to better effect control of the balloon altitude. A parallel pursuit will be the investigation of other balloon types and sizes, in addition to the satisfactory General Mills Polyethylene models now in use. Thus, plans for the future include both the development of control devices currently under test and also a broad, general study of the basic components of constant-level balloon trains from the theoretical as well as the operational viewpoint.